

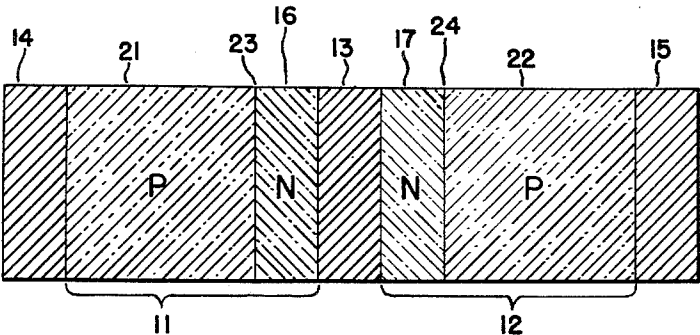
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SEMI-CONDUCTOR DEVICE AND METHOD OF MAKING

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SEMI-CONDUCTOR DEVICE AND METHOD
OF MAKING

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8 Claims. (Cl. 317-234)

The present invention relates in general to semiconductor devices and more particularly concerns a novel voltage reference device characterized by an exceptionally low temperature coefficient and methods of making such devices. Not only is the novel device relatively insensitive to temperature variations, but the desired reference potential is accurately provided even at very low currents. The novel method of making the device facilitates production in large quantities within rigid specifications with relatively few rejects. In addition to the improved electrical performance of the novel voltage reference source, a significant reduction in physical size compared to prior art devices is effected without sacrificing power handling capabilities.

It is well known that a semi-conductor diode may be utilized as a voltage regulator if operated in the saturation region of its inverse characteristic. Diodes used for voltage regulation are frequently referred to as Zener diodes. When the saturation voltage is applied across the diode in the inverse direction, a nearly constant voltage drop is maintained across the diode over a relatively wide current range.

The semi-conductor diode, when used as a regulator or voltage reference, eliminates many of the problems inherent in other types of regulators. It is smaller, lighter in weight, and has a mechanical ruggedness unavailable in electron tubes or batteries. There is essentially no deterioration under storage and little or no aging over its operating life as compared with other regulating devices. Because aging and deterioration are reduced to unimportant factors, the semi-conductor regulator has a long useful life expectancy.

Voltage regulator diodes are preferably made of silicon because silicon devices operate more reliably over wide temperature ranges and are characterized by a relatively high inverse saturation voltage. The saturation voltage of a silicon regulator is determined by the type of silicon material used and is a controllable element in the manufacturing process. This voltage can be predetermined within certain limits for a particular regulator.

The saturation voltage is further dependent upon the operating ambient temperature. The coefficient relating saturation voltage to temperature typically approaches 0.1% per degree C. at higher voltages, passes through 0 in the region around 5.0 volts and is negative at lower voltages. Thus, ideally it would be desired to operate the device where the temperature coefficient is precisely zero. However, it has been difficult in the past to obtain a precise control over saturation voltage and its relation to ambient temperature.

In an effort to provide a silicon regulator with a desired saturation voltage and low temperature coefficient, it was found necessary to select a pair of silicon diodes having similar characteristics near the desired range of saturation voltage and connect them in series, whereby in operation, one was forward-biased, and the other reversed-biased. This has a number of disadvantages. First, the selection process is slow, laborious, and results in a large number of rejects. Second, the resulting physical package is relatively large. Third, an extra step is involved in connecting the two diodes together. Fourth, even after a careful selection process, the desired operating charac-

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teristics of virtually zero temperature coefficient at a prescribed saturation voltage is difficult to obtain.

The difficulties will be better understood by considering the steps required to provide voltage regulators having the desired characteristics in accordance with prior art methods. The inverse saturation voltage of each diode must be measured to within a millivolt at room temperature, high limit temperature and low limit temperature. These readings are then recorded. It is then necessary to examine the records to identify pairs of devices having temperature characteristics related in such a manner that they are likely to cancel when the two diodes are connected in series with regions of like conductivity connected together. The paired diodes must then be individually located from a large group tested in this manner and connected together. Finally, the inverse saturation voltage of the connected-together pairs must be measured at room temperature, high limit temperature and within specified tolerances.

Accordingly, the present invention contemplates and has an important object the provision of a compact silicon voltage regulator characterized by a virtually constant inverse saturation voltage over a wide range of temperatures and operating currents.

It is another object of the invention to provide a semi-conductor voltage regulator in accordance with the preceding object in which the saturation voltage may be specified within relatively close limits.

It is a further object of the invention to provide a method for making semi-conductor voltage regulators in accordance with the preceding objects which minimizes the number of steps required for fabrication, the number of rejects, and the time required to fabricate the novel regulators while providing close control over the operating characteristics of the finished product.

According to broad aspects of the invention, the novel semi-conductor device includes means defining a semi-conducting region having first and second adjacent portions of opposite conductivity type. A layer of silver, having an impurity of the same conductivity type as the second portion, is in contact therewith, a portion of this impurity being diffused into the second portion. To form the novel voltage regulator, two of said means are provided with the layer of silver separating and in contact with the second portions. Ohmic contacts are electrically connected to each first portion. In a preferred form of the invention, the first portions are P-type silicon impregnated with boron and the impurity in the silver is arsenic.

The method of making the novel device includes the steps of placing the silver sheet with the impurities between and in contact with sheets of semi-conductor material, bonding the former sheets to the latter sheets to form a sandwich and heating the sandwich to diffuse at least some of the impurities from the silver to the semi-conductor sheets. The ohmic contacts are then alloyed to the exposed sides of the semi-conductor sheets and the assembly thus formed, diced to size.

Other features, objects and advantages of the invention will become apparent from the following specification when read in connection with the accompanying drawing, the single FIGURE of which shows a cross sectional view of a preferred embodiment of the invention.

With reference now to the drawing, there is shown a sectional view through the novel voltage regulator which illustrates the relationship between the different layers of material forming the device. Since the exemplary embodiment of the novel regulator described herein is of generally rectangular shape, the cross sectional view shown, best illustrates the features of the invention. The

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view is a greatly magnified section through the thickness dimension in order to better illustrate the structure, the size of a typical unit being 0.02" thick by 0.04" square.

Two semi-conducting regions 11 and 12 separate a layer of silver 13 having an N-type impurity, such as arsenic, at a concentration of at least ½% from ohmic contacts 14 and 15, respectively. These contacts may be made of doped gold or other suitable conducting material. Leads may be attached to the ohmic contacts 14 and 15 for connecting the device to an external circuit. The impurity of the silver sheet 13 is also in the portions 16 and 17 of regions 11 and 12, respectively, so that these portions are both N-type as indicated. The portions 21 and 22 of regions 11 and 12 are of P-type conductivity. P-N junctions 23 and 24 are thus formed in regions 11 and 12, respectively.

The preferred method of fabricating the novel voltage regulator, includes the step of first doping silicon with boron to provide a sample of P-type silicon. Boron-doped silicon is preferred because its resistivity may be very accurately controlled due to the high segregation coefficient of boron. This sample of P-type silicon is then sliced to provide slices of preferably the same thickness which define the regions 11 and 12.

Silver is doped with a concentration of at least ½% of arsenic or other suitable N-type doping material. The sheet 13 is formed from the doped silver. The slices of P-type silicon defining regions 11 and 12 are placed in contact with opposite sides of silver sheet 13. The silver is bonded to the two slices by heating the assembly at a temperature of approximately 1,000° C. for at least five minutes in a vacuum or inert atmosphere to form a sandwich. This sandwich is then heated in the same atmosphere to a temperature of approximately 1300° C. for approximately ½ hour to diffuse at least some of the impurities in the silver into the regions 11 and 12 to form the two N-type portions 16 and 17. The latter temperature and time is by way of example only. The time and temperature may be varied to control the inverse saturation voltage of the voltage reference units. Temperatures within the range 1150° C. to 1300° C. and times ranging from ½ hour to six hours are suitable. Thus the saturation voltage may be controlled in three different ways; by controlling the resistivity of the P-type silicon when doping the material with boron, by controlling the diffusion temperature and by controlling the diffusion time. This permits a more precise establishment of the saturation voltage than is possible with the methods of making prior art semi-conductor voltage regulators.

The inverse saturation voltage varies directly as a function of the time temperature product and inversely as a function of the doping concentration in the P-type silicon. A typical value of resistivity for the P-type silicon in a representative embodiment of the invention is 0.02 ohms-cm.

Sheets of ohmic contact material 14 and 15 are then alloyed to the P-type regions 21 and 22. After this alloying step, the assembly may be diced to form the individual voltage regulating units. These units are encapsulated with leads electrically connected to each of the ohmic contacts 14 and 15.

Each unit is a double diode, that is, each has a normal inverse characteristic, regardless of the polarity of the voltage applied across contacts 14 and 15 because one of the junctions 22 and 23 is forward-biased while the other is reversed-biased. Thus before marking the encapsulated unit with the recommended polarity orientation, the saturation voltage in both directions may be determined. The polarity orientation resulting in a saturation voltage closer to the prescribed value is selected

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for normal operation. This approximately doubles the yield of units falling within a narrow prescribed voltage range.

It is unnecessary to match and separately encapsulate in order to obtain a low temperature coefficient. Two diodes effectively in series are provided having temperature coefficients of very nearly the same magnitude but of opposite sense. Hence, the effects due to the temperature variations cancel, and the saturation voltage is virtually insensitive to temperature. Typically, units are regularly produced having a nominal saturation voltage of 6.2 volts over a current range from 0.1 milliampere to 10 milliamperes with a temperature coefficient of 0.005%. Despite this exceptional performance, the physical size of the unit may be fully encapsulated in a cylinder 0.4" long and 0.25" in diameter.

The particular materials, times and temperatures described herein are by way of example, for illustrating the best mode now contemplated for practicing the invention. Numerous modifications of and departures from the specific materials and techniques disclosed may now be practiced by those skilled in the art without departing from the inventive concepts. Consequently, the invention is to be construed as limited only by the spirit and scope of the appended claims.

What is claimed is:

1. A semi-conductor device comprising, first and second means defining semi-conducting regions each having first and second adjacent portions of opposite conductivity with a rectifying junction therebetween each first portion being of the same conductivity type, a layer of silver in contact with and separating both second portions and having an impurity of the same type conductivity as a potential between said first portions B', said layer interconnecting said first and second means so that said rectifying junctions therein are coupled in series and exhibit diode action but prevented thereby from exhibiting transistor action, and means for applying a potential between said first portions.

2. A semi-conductor device in accordance with claim 1, wherein both of said means are formed primarily of silicon.

3. A semi-conductor device in accordance with claim 2, wherein both said first portions are formed of P-type silicon.

4. A semi-conductor device in accordance with claim 3, wherein each of said first portions is doped with boron and said impurity is arsenic.

5. A semi-conductor device in accordance with claim 4, wherein the concentration of said arsenic with respect to said silver is at least one-half percent.

6. A semi-conductor device in accordance with claim 1, and further comprising first and second ohmic contacts electrically connected to respective ones of said first portions.

7. A semi-conductor device in accordance with claim 6, wherein the resistivity of said first and second means is substantially the same.

8. A voltage reference device comprising, first and second means defining semi-conducting regions each having first and second adjacent portions of opposite conductivity, with a rectifying junction therebetween each first portion being of the same conductivity type, and a layer of conducting material having an impurity of the same type conductivity as said second portion in contact with and separating both second portions, said layer interconnecting said first and second means so that said rectifying junctions therein are coupled in series and exhibit diode action but prevented thereby from exhibiting transistor action, and means for applying a potential between said first portions.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,069,603

December 18, 1962

Windsor H. Hunter

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 4, line 30, after "therebetween" insert a comma;
line 34, strike out "a potential between said first portions
B'", and insert instead -- said second portion --; same
column 4, line 64, after "therebetween" insert a comma.

Signed and sealed this 18th day of June 1963.

SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents

