United States Patent [19]

Edmond

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[54] **METHOD OF PRODUCTION OF LIGHT EMITTING DIODES**

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[51] **Int. Cl.**[5] **H01L 31/0312**

[52] **U.S. Cl.** **437/100**; 437/226; 437/181; 437/905; 437/906

[58] **Field of Search** 437/100, 226, 227, 905, 437/906

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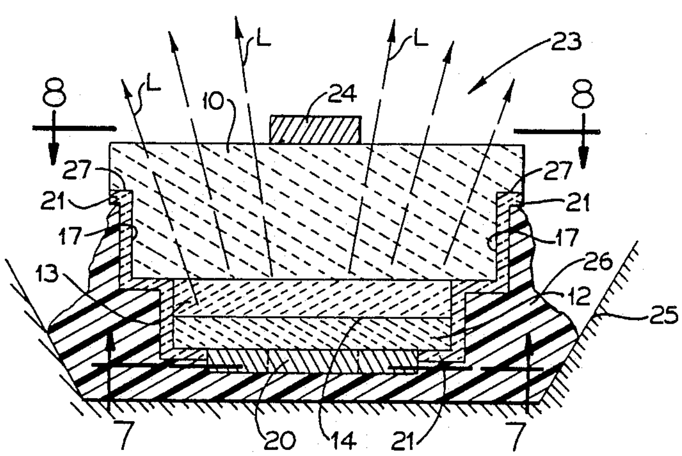
[57] **ABSTRACT**

The invention is a method for preparing a plurality of light emitting diodes on a single substrate of a semiconductor material. The method is used for structures where the substrate includes an epitaxial layer of the same semiconductor material that in turn comprises layers of p-type and n-type material that define a p-n junction therebetween. The epitaxial layer and the substrate are etched in a predetermined pattern to define individual diode precursors, and deeply enough to form mesas in the epitaxial layer that delineate the p-n junctions in each diode precursor from one another. The substrate is then grooved from the side of the epitaxial layer and between the mesas to a predetermined depth to define side portions of diode precursors in the substrate while retaining enough of the substrate beneath the grooves to maintain its mechanical stability. Ohmic contacts are added to the epitaxial layer and to the substrate and a layer of insulating material is formed on the diode precursor. The insulating layer covers the portions of the epitaxial layer that are not covered by the ohmic contact, any portions of the one surface of the substrate adjacent the mesas, and the side portions of the substrate. As a result, the junction and the side portions of the substrate of each diode are insulated from electrical contact other than through the ohmic contacts. When the diodes are separated they can be conventionally mounted with the junction side down in a conductive epoxy without concern that the epoxy will short circuit the resulting diode.

16 Claims, 2 Drawing Sheets



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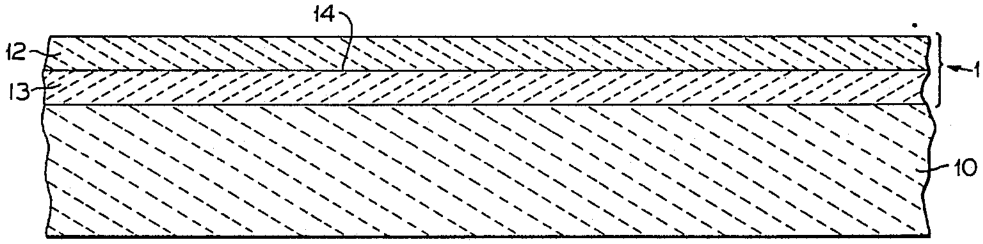

FIG.1.

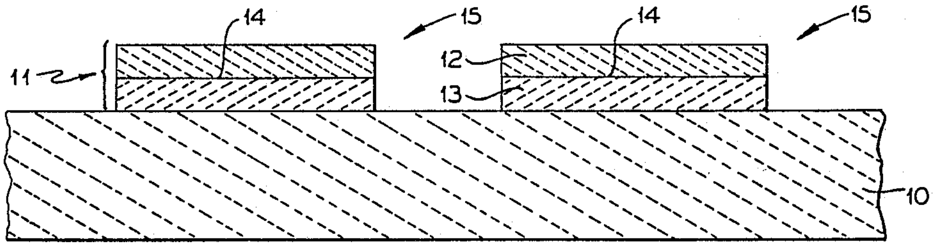

FIG.2.

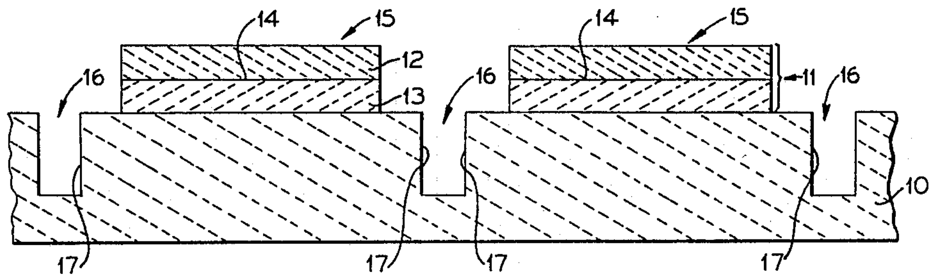

FIG.3.

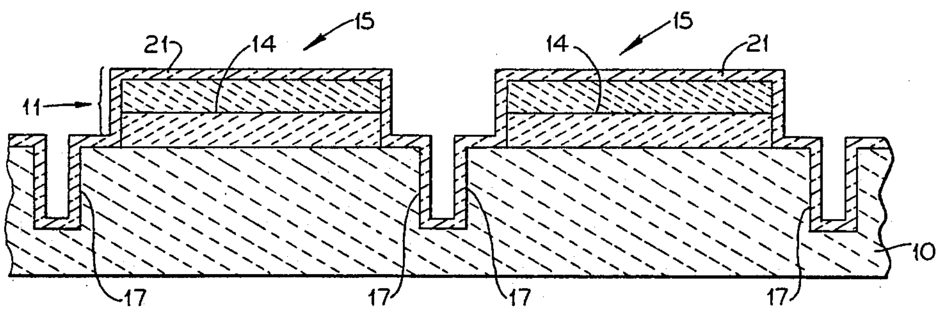

FIG.4.

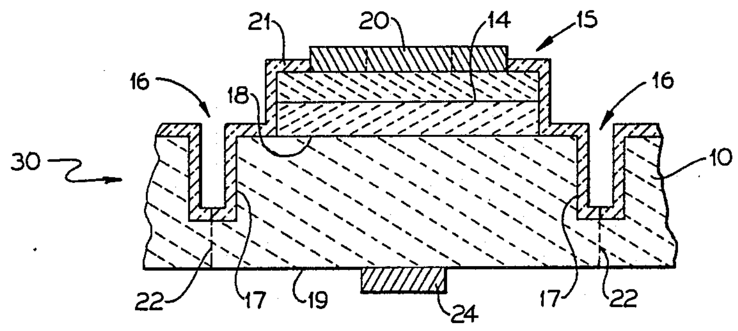

FIG.5.

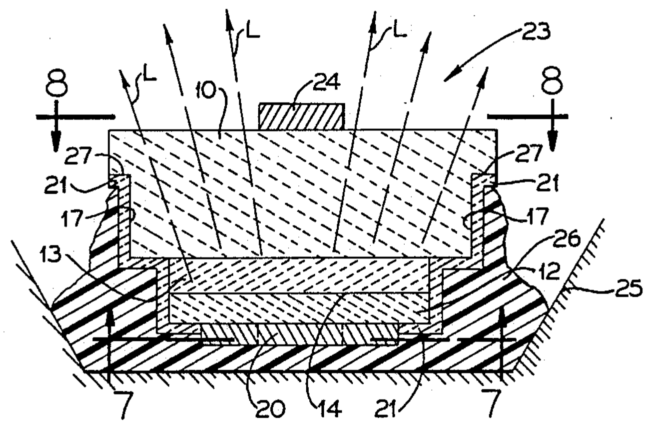

FIG.6.

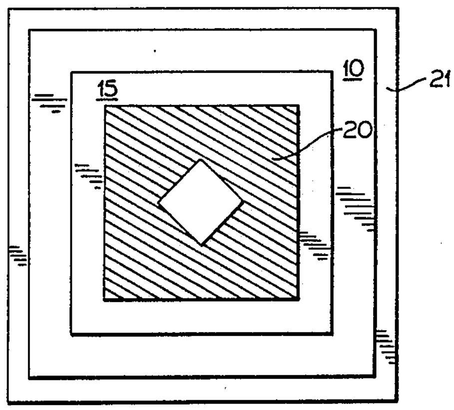

FIG.7.

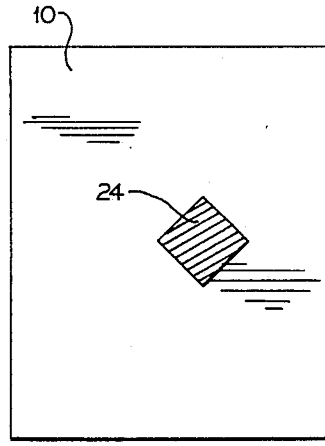

FIG.8.

METHOD OF PRODUCTION OF LIGHT EMITTING DIODES

FIELD OF THE INVENTION

The present invention relates to a method of producing light emitting diodes and in particular relates to a method of producing a plurality of blue light emitting diodes from a single substrate or wafer of silicon carbide, and to the light emitting diodes which result. This application is related to co-pending application Ser. No. 07/284,293, Filed Dec. 14, 1988 to Edmond for "Blue Light Emitting Diode Formed In Silicon Carbide," which is incorporated entirely herein by reference.

BACKGROUND OF THE INVENTION

Light emitting diodes, commonly referred to as "LED's", are semiconductor devices which convert electrical energy into light. As is known to those familiar with semiconducting materials, diodes formed from certain types of materials will produce energy in the form of light when current passes across the p-n junction in such a semiconducting diode. When current passes across a diode's junction, electronic events occur that are referred to as "recombinations," and in which electrons in the semiconductor combine with vacant energy level positions, referred to as "holes," in the semiconductor. These recombination events are typically accompanied by the movement of an electron from a higher energy level to a lower one in the semiconductor material. The energy difference between the energy levels determines the amount of energy that is be given off. When the energy is given off as light (i.e. as a photon), the difference in energy levels results in a particular corresponding wavelength of light being emitted. Because the positions of various available energy levels are a fundamental characteristic of any particular element or compound, the color of light that can be produced by an LED is primarily determined by the semiconductor material in which the recombination is taking place. Additionally, the presence in the semiconductor material of added dopant ions, which are referred to as either "donors" because they provide extra electrons, or as "acceptors" because they provide additional holes, results in the presence of additional energy levels in the semiconductor material between which electrons can move. This in turn provides different amounts of energy that are given off by the available transitions and provides other characteristic wavelengths of light energy given off by these additionally available transitions.

Because of this relationship between energy and wavelength—which in the visible portion of the electromagnetic spectrum represents the color of the light—blue light can only be produced by a semiconductor material having a band gap larger than 2.6 electron volts (eV). The "band gap" refers to the basic energy transition in a semiconductor between a higher or "conduction" band energy level and a more regularly populated lower or "valence" energy band level. For example, materials such as gallium phosphide (GaP) or gallium arsenide (GaAs) cannot produce blue light because the band gaps are on the order of about 2.26 eV or less. Instead, a blue light emitting solid state diode must be formed from a semiconductor with a relatively large band gap such as gallium nitride (GaN), zinc sulfide (ZnS), zinc selenide (ZnSe) and alpha silicon carbide (also characterized as "hexagonal" or "6H silicon carbide," among other designations. Accordingly, a number of investigators have attempted to produce blue light emitting diodes using alpha silicon carbide.

Nevertheless, silicon carbide has not presently reached the full commercial position in the manufacture of electronic devices, including light emitting diodes, that would be expected on the basis of its otherwise excellent semiconductor properties and its potential for producing blue LED's. For example, in addition to its wide band gap, silicon carbide has a high thermal conductivity, a high saturated electron drift velocity, and a high breakdown electric field. All of these are desirable properties in semiconductor devices including LED's. The failure of silicon carbide LED's to reach commercial success appears to be the result of the difficulties encountered in working with silicon carbide. In particular, high process temperatures are required, good starting materials are typically difficult to obtain, particular doping techniques have heretofore been difficult to accomplish, and perhaps most importantly, silicon carbide crystallizes in over 150 polytypes, many of which are separated by very small thermodynamic differences.

Accordingly, the goal of controlling the growth of single crystals or monocrystalline thin films of silicon carbide which are of sufficient quality to make electronic devices such as diodes practical, useful, and commercially viable, has eluded researchers in spite of years of diligent effort, much of which is reflected in both the patent and nonpatent literature.

Recently, however, a number of developments have been accomplished which offer the ability to grow large single crystals of device quality silicon carbide, to grow thin films of device quality silicon carbide, to successfully etch silicon carbide, and to introduce dopants into silicon carbide, all steps that are typically required in the manufacture of LED's and other electronic devices. These developments are the subject of co-pending patent applications that have been assigned or exclusively licensed to the common assignee of the present invention and which are incorporated entirely herein by reference. In addition to the application mentioned earlier, these include Davis et al, "Growth of Beta-SiC Thins Films and Semiconductor Devices Fabricated Thereon," Ser. No. 113,921, Filed Oct. 26, 1987; Davis et al, "Homoepitaxial Growth of Alpha-SiC Thin Films and Semiconductor Devices Fabricated Thereon," Ser. No. 113,573, Filed Oct. 26, 1987; Davis et al, "Sublimation of Silicon Carbide to Produce Large, Device Quality Single Crystals of Silicon Carbide," Ser. No. 113,565, Filed Oct. 26, 1987; Palmour, "Dry Etching of Silicon Carbide, Ser. No. 116,467, filed Nov. 3, 1989; and Edmond et al, "Implantation and Electrical Activation of Dopants Into Monocrystalline Silicon Carbide," Ser. No. 113,561, Filed Oct. 26, 1987.

As set forth in some detail in the Edmond '293 application, a number of different doping techniques and basic device structures are used to produce light of approximately 424–428 nanometers (nm), light of approximately 455–460 nm, and light of approximately 465–470 nm in diodes formed from silicon carbide. Although describing the visible colors of these wavelengths is somewhat of a generalization, the 424–428 nm light has a characteristic violet color, the 455–460 nm transition gives a more medium blue color, and the 465–470 nm transition gives a characteristic light blue color.

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