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# PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

## Method of Making a Junction in a Semiconductor Body

We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organised according to the laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method of making a junction in a semiconductor body. While the invention may be applied to a wide variety of structures, it is particularly suitable for making interdigitated devices.

Interdigitated devices find use in a variety of applications, particularly for microwave and switching circuits. Such devices often require quite shallow diffusion regions having extensive interdigitated geometry. With the prior art methods of forming junctions, for example by standard diffusion technique, the degree of resolution possible in the formation of doped regions has been rather limited, typically in the range of from about one to ten microns maximum resolution. Moreover, prior art technique for forming doped regions of a shallow but precise depth conforming to a predetermined desired value has been far from satisfactory.

Accordingly, an object of the present invention is to provide a method of making a junction for a semiconductor body by which a doped region may be formed in the body in accordance with a pattern having very high resolution complex geometry and a precisely controlled depth, which may be quite shallow if desired.

The present invention provides a method of making a junction in a semiconductor body comprising:

providing a layer of dopant on the surface and/or in a surface region of the semiconductor body, the layer being relatively thin compared with the thickness of the semiconductor body,

exposing the surface of the said layer to focussed energy in accordance with a predetermined pattern to cause dopant to diffuse from the said layer into the said body in accordance with the said pattern, and

removing the dopant from said body except for that dopant diffused into the body by the focussed energy, the dopant being removed by vapour etching while the said body is heated.

In one embodiment the body is heated in a furnace while vapour etching is accomplished, or, in an alternative embodiment a rastering focussed energy source is utilized to provide highly localized heating for the body during the course of vapour etching. In both cases, the body is at an elevated temperature in the region where etching is accomplished.

For a more complete understanding of the present invention and the advantages thereof, reference may now be had to the following description of preferred embodiments taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a schematic elevational section of a silicon slice;

FIGURE 2 shows the slice of FIGURE 1 after a dopant layer has been provided in the upper surface regions of the slice;

FIGURE 3 illustrates the exposure of a predetermined location on the slice to a concentrated energy source such as an electron beam or a laser; and

FIGURE 4 illustrates the structure of FIGURE 3 after the upper dopant region or layer has been removed from the slice.

Turning now to FIGURE 1, therein is illustrated slice 11 of semiconductor

[Price 5s. 0d.]

material, for example, silicon, germanium, gallium arsenide, or other desired semiconductor material. As is illustrated in FIGURE 2, a thin layer of dopant material 13 is provided in a surface region of the slice 11. This may be accomplished for silicon by a standard furnace diffusion, as with boron tribromide in a slightly oxidizing atmosphere for a period of several minutes, for example about ten minutes. Such a layer may be of a thickness of about two microns or less, for example. Alternatively, a thin layer of dopant may be painted to overlie a surface region of slice 11. As an additional alternative, a diffusion layer may be provided by depositing a doped semiconductor layer by conventional epitaxial deposition technique.

After providing the layer of dopant 13, electron beam E, or energy from some other focused energy source, is caused to impinge on the dopant rich surface of the slice 11, as is schematically illustrated in FIGURE 3. The localized effect of the beam, presumably as a result of intense localized heat, causes diffusion in the slice region which underlies the point of exposure of the beam. Accordingly, a diffusion region 15 is formed in the slice 11. The depth of this region may be varied as desired by properly selecting the time of exposure and the intensity of the focused energy source. Moreover, the width of the region 15 may be varied by changing the width of the beam E. Width resolution of a fraction of a micron may be achieved. The beam E may be moved around in accordance with a complex predetermined pattern in order to provide any desired geometry. It will be appreciated that a considerable amount of such beam movement is required in order to make regions for an interdigitated device of complex configuration.

After the exposure to the concentrated energy source is completed, the slice 11 is placed in a furnace and heated to about 900°C. Hydrochloric acid vapor is introduced into the furnace and etching of the layer 13 is effected. Such vapor etch can be precisely controlled to desired depth, and for this reason the depth of the diffusion zone 15 in slice 11 may be maintained at a precise predetermined value, as little as a fraction of a micron.

The end product of processing, with the dopant layer 13 removed, is illustrated in FIGURE 4.

An alternate method to remove the dopant layer from the slice is to utilize a rastering focused energy source, for example an electron beam, to locally heat the surface while providing an HCl vapor atmosphere adjacent to the surface. As another alternative, a pulsed beam may be used to remove dopant, if desired.

The following specific examples are presented merely for purpose of illustration and are not intended to limit the scope of the present invention:

EXAMPLE 1

A silicon slice was processed in accordance with standard furnace diffusion technique in an atmosphere containing boron tribromide to provide a boron-doped diffusion layer of 2 microns depth. The carrier concentration in the layer was approximately $10^{20}$ atoms per cubic centimeter. An electron beam was impinged on the surface of the diffusion layer. The conditions of operation were as follows:

| | |
|---|---|
| Beam energy | 100 KeV |
| Beam current | $0.05 \times 10^{-3}$ amperes |
| Beam diameter | 4 mils |
| Vacuum conditions | $1 \times 10^{-5}$ Torr |

After exposure it was found that diffusion extended to 18 microns from the surface just below the beam contact. The diffusion was sharp and of substantially the diameter of the beam. All diffusion depths in this example were determined by standard lap and stain technique.

EXAMPLE 2

In this example, the increase in the diode breakdown voltage of a boron tribromide deposited layer of material on silicon was determined. The layer had a breakdown voltage of 18 volts prior to exposing it to an electron beam. The results of the exposure to an electron beam are indicated below:

| *Exposure Time (Second)* | *Total Beam Energy Input (Calories)* | *Breakdown Voltage* |
|---|---|---|
| 0 | | 18 volts |
| 4 | 6.5 | 45 volts |
| 8 | 9.5 | 70 volts |
| 6 | 14.0 | 100 volts |

The beam was operated at a beam energy of 100 KeV, and the beam diameter was 0.002 inches.

Certain ferrite and insulator materials, e.g. titanium dioxide, possess semiconductor properties, and in such instances the present invention is applicable to them, and it is intended that they be included with the term "semiconductor", as used herein.

By the present invention, diffusion regions having a diameter as little as a fraction of a micron, e.g. about one-hundredth of a micron, may be formed by maintaining the diameter of the focused energy source at a comparable value.

The present invention may be utilized to make multiple junctions, if desired. Thus, the structure of FIGURE 4 might contain a plurality of regions such as 15, formed by the same technique and having the same or varied geometry, if desired.

By pulsing the focused energy source, material may be removed from the surface

of a diffusion region formed by practice of the present invention without causing any appreciable further diffusion. Alternatively, by maintaining the focused energy source at a low energy level for several seconds the upper surface of a diffusion region, or surface adjacent it, may be caused to rise into a hill-like formation as disclosed in United States Patent Specification No. 3,453,723, assigned to the assignee of the present invention. Combinations of depressions and hills may be made to produce desired geometry involving one or more diffusion regions formed by practice of the present invention.

While the present invention has been described in conjunction with the use of an electron beam as a focused energy source, other focused energy sources may be used as they are available, for example a laser may be utilized.

In certain instances, it is advantageous to heat the semiconductor body or slice being processed in order to minimize thermal gradients in the localized areas of contact with the concentrated energy source. For example, a slice may be maintained at a temperature of 500°C. during the period of time that it is exposed to a focused energy source.

In making certain structures by practice of the present invention, it will be desirable to control the impurity gradient to provide certain characteristics. In certain such instances the technique of out-diffusing is valuable. Our co-pending U.K. Application No. 39911/67 (Serial No. 1,194,048) contains a description of how such out-diffusion may be practised utilizing a focused energy source.

The present invention is not limited to any particular semiconductor materials, nor is it limited to any specific dopants. It is only necessary that a layer of dopant be provided on the surface or in a surface region of a semiconductor body, and that the body be subjected to contact with energy from a focused energy source in accordance with a predetermined pattern. After removal of the layer of dopant by vapor etching the heated semiconductor body, a semiconductor body having a doped region of desired geometry, and of desired resolution and depth, is obtained as a product.

Having described the invention in connection with certain specific embodiments thereof, it is to be understood that further modifications may now suggest themselves to those skilled in the art and it is intended to cover such modifications as fall within the scope of the appended claims.

WHAT WE CLAIM IS:—

1. A method of making a junction in a semiconductor body comprising:

providing a layer of dopant on the surface and/or in a surface region of the semiconductor body, the layer being relatively thin compared with the thickness of the semiconductor body,

exposing the surface of the said layer to focussed energy in accordance with a predetermined pattern to cause dopant to diffuse from the said layer into the said body in accordance with the said pattern, and

removing the dopant from said body except for that dopant diffused into the body by the focussed energy, the dopant being removed by vapour etching while the said body is heated.

2. A method as claimed in claim 1, wherein the body is heated in a furnace.

3. A method as claimed in claim 1, wherein the body is heated by describing a raster on the surface of the body with a focussed energy beam.

4. A method as claimed in any preceding claim, wherein said layer of dopant is provided by epitaxial deposition of doped semiconductor material or by painting, or by diffusion.

5. A method as claimed in claim 3, wherein the body is heated over a selected area by the raster described by the focussed energy beam and at least the said selected area is simultaneously exposed to an etchant vapour.

6. A method as claimed in any preceding claim, wherein the vapour etching comprises use of mineral acid vapour.

7. A method as claimed in any preceding claim, wherein the vapour etching is effected by hydrochloric acid vapour.

8. A method as claimed in any preceding claim, wherein the layer of dopant is 2 microns or less in thickness.

9. A method as claimed in any preceding claim, wherein the focussed energy is an electron beam.

10. A method as claimed in any one of claims 1 to 8, wherein the focussed energy is a laser beam.

11. A method as claimed in any preceding claim, wherein the body is heated overall during and in addition to the exposure to the said focussed energy.

12. A method of making a junction in a semiconductor body substantially as herein described with reference to the accompanying drawings.

13. A semiconductor device including a junction formed by a method according to any preceding claim.

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of a diffusion region formed by practice of the present invention without causing any appreciable further diffusion. Alternatively, by maintaining the focused energy source at a low energy level for several seconds the upper surface of a diffusion region, or surface adjacent it, may be caused to rise into a hill-like formation as disclosed in United States Patent Specification No. 3,453,723, assigned to the assignee of the present invention. Combinations of depressions and hills may be made to produce desired geometry involving one or more diffusion regions formed by practice of the present invention.

While the present invention has been described in conjunction with the use of an electron beam as a focused energy source, other focused energy sources may be used as they are available, for example a laser may be utilized.

In certain instances, it is advantageous to heat the semiconductor body or slice being processed in order to minimize thermal gradients in the localized areas of contact with the concentrated energy source. For example, a slice may be maintained at a temperature of 500°C. during the period of time that it is exposed to a focused energy source.

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removing the dopant from said body except for that dopant diffused into the body by the focussed energy, the dopant being removed by vapour etching while the said body is heated.

2. A method as claimed in claim 1, wherein the body is heated in a furnace.

3. A method as claimed in claim 1, wherein the body is heated by describing a raster on the surface of the body with a focussed energy beam.

4. A method as claimed in any preceding claim, wherein said layer of dopant is provided by epitaxial deposition of doped semiconductor material or by painting, or by diffusion.

5. A method as claimed in claim 3, wherein the body is heated over a selected area by the raster described by the focussed energy beam and at least the said selected area is simultaneously exposed to an etchant vapour.

6. A method as claimed in any preceding claim, wherein the vapour etching comprises use of mineral acid vapour.

7. A method as claimed in any preceding claim, wherein the vapour etching is effected by hydrochloric acid vapour.

8. A method as claimed in any preceding claim, wherein the layer of dopant is 2 microns or less in thickness.

9. A method as claimed in any preceding claim, wherein the focussed energy is an electron beam.

10. A method as claimed in any one of claims 1 to 8, wherein the focussed energy is a laser beam.

11. A method as claimed in any preceding claim, wherein the body is heated overall during and in addition to the exposure to the said focussed energy.

12. A method of making a junction in a semiconductor body substantially as herein described with reference to the accompanying drawings.

13. A semiconductor device including a junction formed by a method according to any preceding claim.

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