"BURIED HETERO-STRUCTURE OPTO-ELECTRONIC DEVICE"

THIS INVENTION relates to buried hetero-structure opto-electronic devices, and in particular to buried hetero-structure semiconductor lasers.

Buried hetero-structure semiconductor lasers have become widely-used in recent years as laser sources for, for example, optical communication systems. In a conventional buried hetero-structure semiconductor laser, an active layer (i.e. the layer in which the photons constituting the laser are actually generated) of a semiconductor material is buried within a larger bandgap semiconductor material. Semiconductor layers surrounding the active layer are grown to create a reverse biased junction, the active layer being positioned in a gap in the reverse biased junction. In operation of the device, electrical current flows across the semiconductor layers, substantially perpendicularly thereto. The reverse biased junction provides resistance to this, and the flow of current is directed through the gap in the reverse-biased junction, and hence through the active layer.

This structure does, however, suffer from drawbacks, in that, under high temperature and high output power operation, the flow of current across the device can be sufficient to drive electrons across the reversed biased junction, thereby drastically reducing the effectiveness of the device.

A further drawback of the above-described semiconductor laser is that the conventional fabrication process of such a device is rather complicated, as sufficient layers of appropriately doped semiconductor material to create a p-n-

p-n thyristor must be grown in the correct order during manufacture of the device.

It is an object of the present invention to seek to alleviate some or all of these disadvantages.

Accordingly, one aspect of the present invention provide a method of manufacturing a semiconductor optical device comprising the steps of: providing a substrate having an active layer thereon; providing an aluminium-bearing layer, the aluminium bearing layer being adjacent the active layer; and oxidising the aluminium-bearing layer substantially entirely.

Advantageously, the method further comprises the step of providing a mesa on the substrate and wherein the step of providing an active layer comprises the step of providing an active layer on the mesa.

Preferably, the step of providing a mesa on the substrate comprises the steps of: providing a substrate; and wet etching the substrate to form a mesa.

Conveniently, the step of providing a mesa on the substrate comprises the steps of: providing a substrate; and reactive ion etching the substrate to form a mesa.

Advantageously, the method further comprises the step of etching at least one groove in the device to a depth at least equal to that of the aluminium-bearing layer.

Preferably, the step of etching at least one groove in the device comprises the steps of: providing an etching mask an upper surface of the device, the etching

mask having an elongate gap therein; and applying an etching process to the device.

Conveniently, the method further comprises the step of providing at least one further groove in the device, the at least one further groove being substantially parallel to the first groove.

Advantageously, the method further comprises the step of providing a cladding layer on top of the active layer or the aluminium-bearing layer.

Preferably, the method further comprises the step of providing a contact layer on the uppermost layer of the device.

Conveniently, the method further comprises the step of providing a first electrode on the device.

Advantageously, the method further comprises the step of providing a second electrode on an opposite side of the device from the first electrode.

Preferably, the step of providing an aluminium-bearing layer or the step of providing an active layer comprises the step of growth by a low pressure metal-organic vapour phase epitaxial technique.

Conveniently, the method further comprises the step of depositing a dielectric film on a layer of the device.

Advantageously, the step of depositing a dielectric film comprises the step of deposition by a plasma chemical vapour deposition method.

Preferably, the step of oxidising the aluminium-bearing layer substantially entirely comprises the step of heating the device in water-containing environment at a temperature of about 350 to 550°C.

Conveniently, the water-containing environment is generated by the flow of a gas through water heated to about 80 to 90°C for about half an hour to about 10 hours.

A further aspect of the present invention provides a semiconductor optical device comprising: a substrate having an active layer formed thereon; and an aluminium-bearing layer, wherein the aluminium-bearing layer is adjacent the active layer and is oxidised substantially entirely.

Advantageously, a mesa is formed on the substrate, the active layer being located on the mesa.

Preferably, the device further comprises first and second electrodes on opposing sides thereof.

Conveniently, the device further comprises a cladding layer provided on the active layer or the aluminium-bearing layer.

Advantageously, the aluminium-bearing layer is substantially continuous apart from the region of the substrate on which the active layer is formed, thereby allowing electric current to flow from a first side of the device to a second side of the device only through the active layer.

In order that the present invention may be more readily understood, embodiments thereof will now be described, by way of example, and with reference to the accompanying drawings, in which:

Figures 1 to 6 show first to sixth stages in the fabrication of an opto-electric device embodying the present invention.

Turning firstly to Figure 1, the first step in the manufacture of a device embodying the present invention is the provision of a n-(negatively doped) InP substrate 1 which is preferably formed of a semiconductor material. The doping concentration of the substrate 1 is preferably in the region of 10^{18} cm^{-3}. The substrate 1 is etched to provided a mesa 2, in the form of an elongated, raised strip, along the <011> direction of the substrate. The height of the mesa is preferably less than 2μm, and the width of the mesa is preferably in the region of 2-2.5μm. A top surface 3 of the mesa 2 is substantially parallel to that of the substrate 1, and the side walls 4 of the mesa 2 preferably subtend an angle equal to or less than 90° with the surface of the etched substrate 1. The etching of the mesa may be achieved by the use of a two-step wet etching Br mixture followed by a $HBr:H_3PO_4$ mixture. Alternatively, reactive ion etching (employing, for example, CH_4/H_2) could be used. However, it will be clear to a person skilled in the art that many techniques may be employed for the creation of the mesa 2.

A buffer layer 5, which is preferably formed of n-InP semiconductor material, is then grown on the substrate 1, as shown in Figure 2. The doping concentration of the buffer layer 5 is preferably in the region of $8*10^{18}cm^{-3}$. The depth of the buffer layer 5 is less than the height of the mesa 2, so that a top portion of the mesa 2 protrudes above the buffer layer 5. A separate portion 5a of the buffer

layer 5 is deposited on the top surface 3 of the mesa 2, however the separate portion 5a has no contact with the remainder of the buffer layer 5. The depth of the buffer layer 5 is preferably in the region of 0.3μm.

Following the deposition of the buffer layer 5, an active layer 6, which preferably comprises InGaAsP semiconductor material, and an aluminium-bearing layer 7 are formed on the buffer layer 5 as shown in Figure 2. The aluminium-bearing material is preferably formed of $Al_xGa_yIn/_{-x-y}As$ bulk, $Al_xGa_yIn/_{-x-y}As/Al_xGa_yIn/_{-x-y}$ (x being in the range of >0.4 and y being between 0 and 1) mixed multiple layers or AlAsSb semiconductor material. The upper surface of the aluminium-bearing layer 7 is, after deposition on the buffer layer 5 and the active layer 6, approximately equal in height to the upper surface 3 of the mesa 2.

As the active layer 6 and the aluminium-bearing layer 7 are deposited on the buffer layer 5, central portions 6a, 7a, of these layers will be deposited on top of the central region of the buffer layer 5a on top of the mesa 2, the central portions 6a, 7a being approximately equal in thickness to those deposited on the main region of the substrate 1. The central portions 6a, 7a of the active layer 6 and the aluminium-bearing layer 7 are grown separately from the portions of these layers grown on the main region of the substrate 1, due to A preferential crystal regrowth mechanism. The materials comprising the active layer 6 and thealuminium-bearing layer 7 will not grow on the (111)B facets of the mesa 2 (i.e. the side surfaces thereof), and so the regions of these materials grown on the top surface 3 of the mesa 2 are physically separate from those grown on the main region of the substrate 1.

Next, a cladding layer 8, which is preferably formed of p-InP semiconductor material, is deposited on top of the previously-formed layers. The doping concentration of the cladding layer 8 is preferably in the region of $5*10^{17}cm^{-3}$. The cladding layer 8 is of significantly greater thickness than the buffer layer 5, the active layer 6, or the aluminium-bearing layer 7, and a relatively great depth of the cladding layer 8 is formed over these layers. The presence of the raised mesa 2 and the central portions of the buffer layer 5a, active layer 6a and aluminium-bearing layer 7a fomred thereon lead to a central bulge 9 in the top of the cladding layer 8, due to even deposition of this layer over the uneven surface of the previously-formed layers. A p-InGaAs contact layer 10 is grown on the upper surface of the cladding layer 8. The cladding layer 8 and contact layer 10 are shown in Figure 3.

An oxidation protection mask 11, which is preferably formed of $S:O_2$ or $S:_3N_4$, is subsequently formed on top of the contact layer 10. The oxidation protection mask 11 is formed to cover substantially the entire upper surface of the contact layer 10, with the exception of two narrow stripes 12, the stripes 12 being substantially parallel with the mesa 2 and one stripe 12 being either side of the mesa 2 as shown in Figure 4. Etching of the top surface of the deposited layers is then performed.

Due to the presence of the oxidation protection mask 11, only the two stripes 12 of exposed contact layer may be etched. Etching continues until two parallel grooves 13, corresponding to the positions of the two stripes 12, are formed through all the deposited layers, and penetrate the top surface of the substrate 1. The parallel grooves are preferably formed by wet etching, the etching solution being Br or HC1 based. Figure 5 shows the layers once the two grooves 13 have been formed therein. It will be appreciated that a surface of each of the

deposited layers 5, 6, 7, 8, 10 will be exposed on a wall of each of the grooves 13. The walls of the grooves 13 may be substantially perpendicular to the deposited layers (as shown in Figure 5), however this need not to be the case, and the walls may be inclined in either direction.

The next step in the process is to utilise a native oxidation technique to oxidise the aluminium-bearing layer 7. The oxidation is preferably carried out by heating the device in a water-containing environment at a temperature of around 350 to 550°C. Such a moist environment may be generated by flowing a gas, for example, nitrogen, through water heated to about 80 to 90°C. The flow of water vapour is continued for about half an hour to ten hours. The oxidation process continues until substantially all of the aluminium-bearing layer 7 has been oxidised. Clearly, the atmosphere above the device cannot come into contact with the portions of the buffer layer 5a, the active layer 6a and the aluminium-bearing layer 7a that were deposited on the top surface 3 of the mesa 2, as these layers are contained within the cladding layer 8. Hence, the portion of the aluminium-bearing layer 7a that was deposited on the top surface 3 of the mesa 2 does not become oxidised. In a preferred embodiment of the invention, the aluminium-bearing layer 7 has a concentration in the region of $5*10^{17}$ Al atoms cm^{-3}. A high concentration of aluminium expedites the oxidation process, thereby shortening the production time of the device.

In the final stage of the manufacturing process, a dielectric film 14 is deposited over the majority of the upper surface of the contact layer 10. The only region of the contact layer 10 that is not covered by the dielectric film 14 is the bulge 9 on the top surface of the contact layer 10 directly above the mesa 2, and a region to one side thereof. A layer of a conductive metal 15 is deposited on the region of the contact layer 10 that is not covered by the dielectric film 14, as shown in

Figure 6. A further layer of conductive metal 16 is applied to the lower surface of the substrate 1.

Preferably, the above-mentioned epitaxial semiconductor layers are grown by a low pressure metal-organic vapour phase epitaxy (mOVPE) technique. The dielectric film is preferably deposited by a plasma chemical vapour deposition (CVD) method. However, the present invention is not limited to these methods.

In use of the finished device, a current is applied to the device, and made to flow from the positive electrode thereof (formed by the layer of conductive metal 15 on the top surface of the contact layer 10) to the negative electrode thereof (formed by the layer of conductive metal 16 formed on the lower surface of the substrate 1). Current-carrying electrons pass through the contact layer 10 and the cladding layer 8. However the electrons are not able to pass through the oxidised aluminium-bearing layer 7, due to the dielectric properties of oxidised aluminium. As a consequence, the vast majority of the current-carrying electrons are forced to pass through the layers 5a, 6a, 7a formed on the top surface 3 of the mesa 2. Due to the fact that the portion of the aluminium-bearing layer 7a deposited on the top surface 3 of the mesa 2 is not oxidised, this layer 7a does not block the electrons and allows them to pass into the active layer 6a formed on the top surface 3 of the mesa 2. After having passed through the active layer 6a, the current-carrying electrons pass through the part of the buffer layer 5a that is deposited on the mesa 2, through the substrate 1 and into the negative electrode formed by the layer of conductive metal 16 deposited on the lower surface of the substrate 1.

As the electrons pass through the active layer 6a, excitation and de-excitation events between well-defined energy levels in the active layer 6a lead to the

emission of photons of a particular wavelength, giving rise to a laser beam which may leave the device through an end of the active layer 6a. the active layer 6a is, preferably, small enough to support only a single transverse mode of the laser photons. Due to the concentration of the current flowing through the device by the oxidised aluminium-bearing layer 7 through the active layer 6a, the device has a low lasing current threshold. In addition, the fact that the oxidised aluminium-bearing layer 7 blocks the passage of current therethrough by virtue of the insulating properties thereof (rather than providing a reverse-biased semiconductor junction) the above-mentioned drawback of the provision of such junctions (i.e. the driving of electrons across the junction at high operating currents and temperatures) will not occur.

Further advantages are conferred by the structure of the device of the present invention, in that oppositely-doped semiconductor layers are required to form a reversed-biased semiconductor junction. In contrast, only one layer need be deposited to form an insulating oxidised aluminium-bearing layer, and devices embodying the present invention may be manufactured with fewer epitaxial deposition steps than conventional semiconductor lasers. A reduction in the number of epitaxial deposition steps is highly desirable, as these steps are difficult to control and time-consuming to perform.

The present invention may be employed to construct DFB lasers, DBR lasers, FP lasers, optical amplifiers, waveguides, switches or other integrated devices, and is not limited to the above embodiments.

It will be clear to a person skilled in the art that the present invention allows the construction of semiconductor lasers with low lasing thresholds and which perform consistently at high operating temperatures and currents. The present

invention also allows the construction of such high-quality semiconductor lasers with fewer epitaxial deposition steps, leading to a significant reduction in the time and cost required to construct the device.

In the present specification "comprises" means "includes or consists of" and "comprising" means "including or consisting of".

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

CLAIMS

1. A method of manufacturing a semiconductor optical device comprising the steps of:

providing a substrate having an active layer thereon;

providing an aluminium-bearing layer, the aluminium-bearing layer being adjacent the active layer;

oxidising the aluminium-bearing layer substantially entirely; and

providing a mesa on the substrate,

wherein the step of providing an active layer comprises the step of providing an active layer on the mesa

2. A method according to Claim 1, wherein the step of providing a mesa on the substrate comprises the steps of: providing a substrate; and wet etching the substrate to form a mesa.

3. A method according to Claim 1, wherein the step of providing a mesa on the substrate comprises the steps of: providing a substrate; and reactive ion etching the substrate to form a mesa.

4. A method according to any preceding claim, further comprising the step of etching at least one groove in the device to a depth at least equal to that of the aluminium-bearing layer.

5. A method according to Claim 4, wherein the step of etching at least one groove in the device comprises the steps of:

providing an etching mask an upper surface of the device, the etching mask having an elongate gap therein; and

applying an etching process to the device.

6. A method according to Claim 4 or 5, further comprising the step of providing at least one further groove in the device, the at least one further groove being substantially parallel to the first groove.

7. A method according to any preceding claim, further comprising the step of providing a cladding layer on top of the active layer or the aluminium-bearing layer.

8. A method according to any preceding claim, further comprising the step of providing a contact layer on the uppermost layer of the device.

9. A method according to any preceding claim, further comprising the step of providing a first electrode on the device.

10. A method according to Claim 9, further comprising the step of providing a second electrode on an opposite side of the device from the first electrode.

11. A method according to any preceding claim, wherein the step of providing an aluminium-bearing layer or the step of providing an active layer comprises the step of growth by a low pressure metal-organic vapour phase epitaxial technique.

12. A method according to any preceding claim, further comprising the step of depositing a dielectric film on a layer of the device.

13. A method according to Claim 12, wherein the step of depositing a dielectric film comprises the step of deposition by a plasma chemical vapour deposition method.

14. A method according to any preceding claim, wherein the step of oxidising the aluminium-bearing layer substantially entirely comprises the step of heating the device in water-containing environment at a temperature of about 350 to 550°C.

15. A method according to Claim 14, wherein the water-containing environment is generated by the flow of a gas through water heated to about 80 to 90°C for about half an hour to about 10 hours.

16. A semiconductor optical device comprising:

a substrate having an active layer formed thereon;

an aluminium-bearing layer, wherein the aluminium-bearing layer is adjacent the active layer and is oxidised substantially entirely; and

a mesa formed on the substrate, the active layer being located on the mesa.

17. A device according to Claim 16, further comprising first and second electrodes on opposing sides thereof.

18. A device according to any one of Claims 16 or 17, further comprising a cladding layer provided on the active layer or the aluminium-bearing layer.

19. A device according to any one of Claim 16 to 18, wherein the aluminium-bearing layer is substantially continuous apart from the region of the substrate on which the active layer is formed, thereby allowing electric current to flow from a first side of the device to a second side of the device only through the active layer.

20. A method of manufacturing a semiconductor optical device substantially as hereinbefore described, with reference to the accompanying drawings.

21. A semiconductor optical device substantially as hereinbefore described, with reference to the accompanying drawings.

22. Any novel feature or combination of features disclosed herein.