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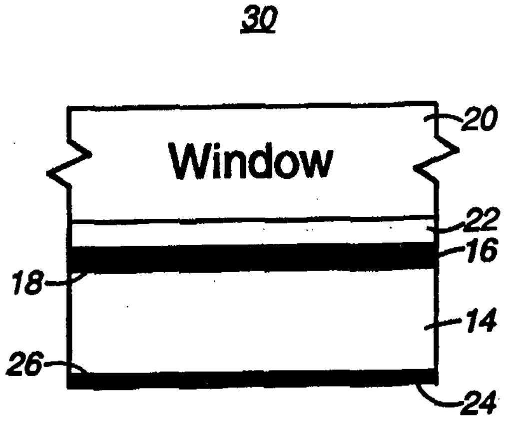
(54) Title: ELECTRON BEAM PUMPED SEMICONDUCTOR LASER SCREEN AND METHOD OF FORMING

(57) Abstract

A method for creating an electron beam pumped semiconductor laser screen (30) requires growing epitaxially an etch stop layer (10) on a gallium arsenide (GaAs) substrate (12). Next a gain region (14) is grown epitaxially on the etch stop layer (10). An output mirror (16) is then formed over the gain region (14). The output mirror (16) is bonded to a transparent support structure (20). Then the gallium arsenide substrate (12) is etched. The etch stop layer (10) is then etched. Finally, a back side mirror (24) is formed on the gain region (14), where the etch stop layer (16) was located.



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ELECTRON BEAM PUMPED SEMICONDUCTOR LASER SCREEN AND METHOD OF FORMING

Field of the Invention

The present invention relates generally to the field of lasers and more particularly to an electron beam pumped semiconductor laser screen and method of producing the electron beam pumped semiconductor laser screen.

Background of the Invention

Electron Beam pumped Semiconductor Lasers (EBSL) are semiconductor lasers that use an electron beam instead of an electrical current to create a population inversion in the semiconductor laser. A typical EBSL contains a cathode ray tube that generates and accelerates electrons at a screen. The screen is a semiconductor material system similar to standard laser diodes. EBSLs have a wide variety of potential applications including; projection displays systems, environmental monitoring and high power lasers. Present EBSLs operating in the visible spectrum are made with laser screens using II-VI (i.e., materials from column 2 & 6 of the periodic table) bulk single crystal semiconductors. Bulk single crystal semiconductors as used herein means thick film crystals that are sliced form a larger piece of the same homogenous material. These EBSLs suffer from low reliability, high anode voltages (high electron beam energies), poor uniformity of color and intensity and require cryogenic cooling.

Thus there exists a need for an EBSL screen that does not suffer from the problems listed above.

Summary of the Invention

A method for creating an electron beam pumped semiconductor laser screen that overcomes these and other problems requires growing epitaxially an etch stop layer on a gallium arsenide (GaAs) substrate. Next a gain region is grown epitaxially on the etch stop layer. An output mirror is then formed over the gain region. The output mirror is bonded to a transparent support structure. Then the gallium arsenide substrate is etched. The etch stop layer is then etched. Finally, a back side mirror is formed on the gain region, where the etch stop layer was located.

Brief Description of the Drawings

FIG. 1 is a schematic drawing of a substrate, an etch stop layer and a gain region and represents a first step in an embodiment of a method of forming an Electron Beam pumped Semiconductor Laser (EBSL) screen according to the invention;

FIG. 2 is a schematic drawing of a second step in an embodiment of the method of forming an EBSL screen according to the invention;

FIG. 3 is a schematic drawing of a third step in an embodiment of the method of forming an EBSL screen according to the invention;

FIG. 4 is a schematic drawing of a fourth step in an embodiment of the method of forming an EBSL screen according to the invention;

FIG. 5 is a schematic drawing of a fifth step in an embodiment of the method of forming an EBSL screen according to the invention;

FIG. 6 is a schematic drawing of an embodiment of an EBSL screen, having a single quantum well, according to the invention;

FIG. 7 is a schematic drawing of an embodiment of an EBSL screen, having a plurality of quantum wells, according to the invention; and

FIG. 8 is a schematic drawing of an embodiment of an operating EBSL screen according to the invention.

Detailed Description of the Drawings

An electron beam pumped semiconductor laser (EBSL) screen having an indium gallium aluminum arsenide phosphide (InGaAlAsP) material system for the gain region can be designed to emit in the red region of the optical spectrum. The InGaAlAsP material system can be grown epitaxially and as a result does not suffer from the problems of the prior art. An etch stop layer 10 is epitaxially grown on a gallium arsenide (GaAs) substrate 12, as illustrated in FIG. 1. A gain region 14 is then grown on the etch stop layer 10. In one embodiment of the invention, the gain region is an InGaAlAsP material system and in this case epitaxial growth is used to form the gain region. In another embodiment, a lattice matching layer(s) is grown on the substrate 12 before the etch stop layer 10 is grown. The epitaxial growth can be performed using any of the growth technologies appropriate to the structure, including metal organic chemical vapor deposition (MOCVD), molecular beam epitaxy, liquid phase epitaxy, or close spaced vapor transport.

The next step (shown in FIG. 2) is to form an output mirror 16 on a first surface 18 of the active gain region 14. In one embodiment the output mirror 16 is formed by epitaxially growing a multi-layered optical output mirror. In another embodiment, the output mirror 16 is formed by deposition of a plurality of dielectric films. The deposition of the dielectric films can be done using: thermal evaporation, sputtering, ion beam deposition, or electron beam deposition. As is well known in the art, the composition and thickness of the layers can be varied to yield the desired output mirror reflectivity.

The third step shown in FIG. 3 is to bond the output mirror 16 to a transparent support structure (window, output window) 20. A transparent optical epoxy (optically transparent epoxy) 22 is used to bond the window 20 to the output mirror 16. In another embodiment the bonding is done with a low melting point glass or with wafer fusion technology. The window 20 is chosen to provide optical transparency to the light emitted by the EBSL, mechanical support, heat conduction from the active gain region 14 to a heatsink and to be chemically inert to any chemical processes that follow. Sapphire (single crystalline Al_2O_3, Sapphire crystal) is used as the output window 20 in one embodiment.

The next step, illustrated in FIG. 4, is to remove the substrate 12 by chemical etching. After the substrate is removed, the etch stop layer is removed with further chemical etching in an etchant that does not etch the active layer materials. The etch stop layer 10 allows the substrate 12 and any lattice matching layers to be chemically dissolved in appropriate etching solutions. Such etchants are well known by those in the art.

The next step, illustrated in FIG. 5, is to deposit a metallic mirror (back side mirror, input mirror, thin metallic film) 24 on a second surface 26 of the active gain region 14. The metal and thickness should be chosen for high reflectivity of the light emitted and low attenuation of the incident high energy electron beam. In one embodiment, the metallic mirror 24 is made of aluminum (Al) or silver (Ag) with a thickness of 100nm or less. This step completes a semiconductor screen (electron beam pumped semiconductor screen) 30. The semiconductor screen 30 is then integrated with a cathode ray tube to complete the EBSL.

FIG. 6 shows another embodiment of the EBSL screen 30, wherein the active gain region includes a quantum well 32. The quantum well 32 provides for more efficient lasing. Another embodiment of the EBSL screen 30 is shown in FIG. 7, where the active gain region includes a multiple, isolated, strained quantum well (MISQW) structure 34. An MISQW is described in more detail in the patent application, application number 08/705732, entitled "Multiple, Isolated Strain Quantum Well Semiconductor Laser", filed on August 30, 1996, assigned to the same assignee as the present application, and hereby incorporated by reference.

FIG. 8 is a schematic diagram of the EBSL. An electron beam 40, generated by a cathode ray tube for example, impinges on the back side mirror 24. The electron beam 40 results in carrier recombination in the EBSL screen 30. The carrier recombination process results in optical emission 42 that is amplified in the standard method for a laser.

A red EBSL can be formed with an InGaAlAsP semiconductor screen. In one embodiment that emits in the red part of the optical spectrum, an MISQW gain region is used. The MISQW contains a plurality of quantum wells of $Al_{0.114}Ga_{0.296}In_{0.59}P$ each 60 to 120 angstroms thick and embedded in a background of $Al_{0.179}Ga_{0.331}In_{0.59}P$. Note that this structure has no arsenic (As) in the layers, and is a special case of the more general AlGaInAsP material. Arsenic containing layers could be incorporated for the substrate removal etching process, but are not actively involved in the laser emission.

Other embodiments include an EBSL screen formed of a GaAlInSbAs (gallium aluminum indium antimonide arsenide) alloy semiconductor. This alloy can be grown epitaxially on a GaAs substrate and therefor can contain quantum wells in the gain structure. Another embodiment uses a HgCdTe (mercury cadmium telluride) material system. This material system is grown epitaxially on a CdTe (cadmium telluride) substrate and may contain a quantum well structure. Other potential material systems include CdZnSeS (cadmium zinc selenide sulfide) grown on GaAs or CdSe, ZnCdS (zinc cadmium sulfide) grown on GaAs and GaAlN (gallium aluminum nitride) grown on sapphire.

Thus, there has been described a unique process for forming an EBSL screen. The etch stop layer allows numerous semiconductor material systems to be formed for use as an EBSL screen, that otherwise would not be good candidates for an EBSL screen. Using this process it is possible to grow an InGaAlAsP semiconductor screen that lases in the red region of the optical spectrum.

While the invention has been described in conjunction with specific embodiments thereof, it is evident that many alterations, modifications, and variations will be apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended to embrace all such alterations, modifications, and variations in the appended claims.

Claims

What is claimed is:

1. A method for creating an electron beam pumped semiconductor laser screen comprising:

(a) growing epitaxially an etch stop layer on a gallium arsenide (GaAs) substrate;
(b) growing epitaxially a gain region on the etch stop layer;
(c) forming an output mirror over the gain region;
(d) bonding the output mirror to a transparent support structure;
(e) etching the gallium arsenide substrate;
(f) etching the etch stop layer; and
(g) forming a back side mirror on the gain region where the etch stop layer was located.

2. The method of claim 1, wherein step (b) includes the step of growing a gain structure from an indium gallium aluminum arsenide phosphide (InGaAlAsP) material system.

3. The method of claim 1, wherein the active region lases in a red region of an optical spectrum.

4. The method of claim 1, wherein step (b) includes the step of forming a quantum well in the active gain region.

5. The method of claim 1, wherein step (b) includes the step of forming a multiple, isolated, strained quantum well structure.

6. The method of claim 1, wherein step (c) includes the step of epitaxially growing the output mirror.

7. The method of claim 1, wherein step (c) includes the step of depositing a plurality of dielectric films to form the output mirror.

8. The method of claim 1, wherein step (d) includes the step of adhering a sapphire crystal with an optically transparent epoxy to the output mirror.

9. The method of claim 1, wherein step (d) includes the step of adhering a sapphire crystal to the output mirror using wafer bonding.

10. The method of claim 1, wherein step (g) includes the step of depositing a thin metallic film.

11. An electron beam pumped semiconductor laser screen comprising:

an output mirror;

a gain region having a first surface adjacent the output mirror, the gain region formed from an indium gallium aluminum arsenide phosphide (InGaAlAsP) material system; and

a metallic mirror attached to a second surface of the gain region.

12. The electron beam pumped semiconductor laser of claim 11, further including an output window bonded to the output mirror.

13. The electron beam pumped semiconductor laser of claim 11, wherein the output window is formed of a sapphire crystal.

14. The electron beam pumped semiconductor laser of claim 13, further including a transparent optical epoxy to bond the output mirror to the sapphire crystal.

15. The electron beam pumped semiconductor laser of claim 11, wherein the gain region includes a quantum well.

16. The electron beam pumped semiconductor laser of claim 11, wherein the gain region includes a multiple, isolated, strained quantum well structure.

17. The electron beam pumped semiconductor laser of claim 16, wherein the gain region lases in a red region of an optical spectrum.

18. The electron beam pumped semiconductor laser of claim 11, wherein the metallic mirror is made from a metal selected from the group of aluminum and silver.

19. The electron beam pumped semiconductor laser of claim 17, wherein the metallic mirror has a thickness no greater than 100 nanometers.

20. A method for creating an electron beam pumped semiconductor laser screen comprising:

(a) growing an etch stop layer on a substrate;
(b) growing an active region on the etch stop layer;
(c) forming an output mirror on the active region;
(d) removing the substrate and the etch stop layer; and
(f) forming an input mirror over the active region where the etch stop layer was located.

21. The method of claim 20, wherein step (b) includes the step of epitaxially growing a gallium aluminum indium antimonide arsenide material system.

22. The method of claim 20, wherein step (b) includes the step of epitaxially growing a mercury cadmium telluride material system.

23. The method of claim 20, wherein step (b) includes the step of epitaxially growing a cadmium zinc selenide sulfide material system.

24. The method of claim 20, wherein step (b) includes the step of epitaxially growing a zinc cadmium sulfide material system.

25. The method of claim 20, wherein step (b) includes the step of epitaxially growing a gallium aluminum nitride material system.

26. The product formed by the method of claim 20.

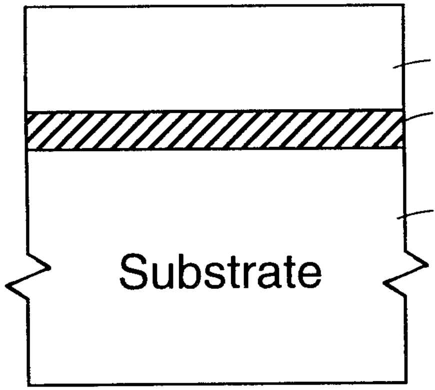

FIG. 1

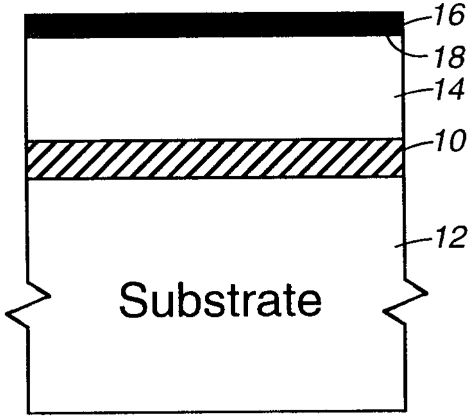

FIG. 2

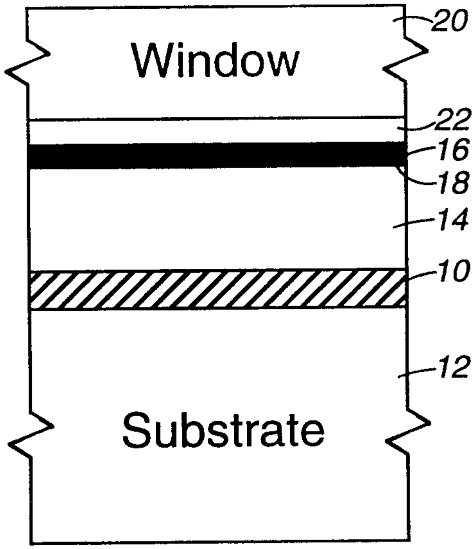

FIG. 3

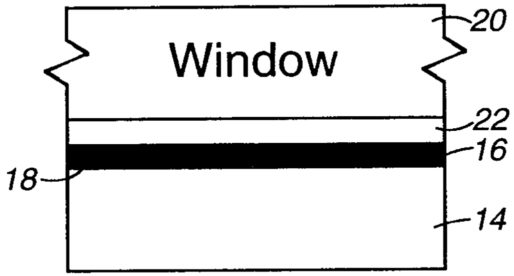

FIG. 4

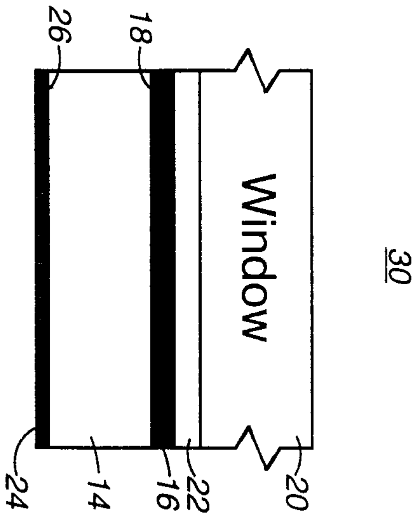

FIG. 5

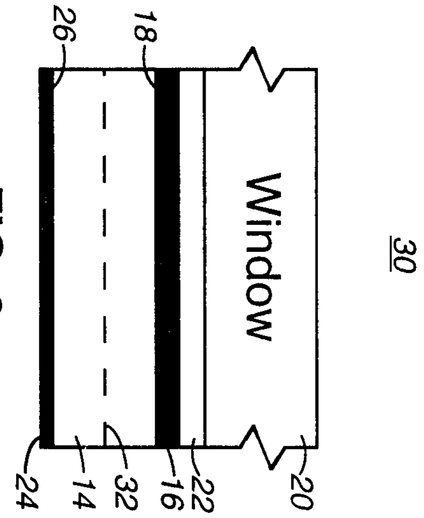

FIG. 6

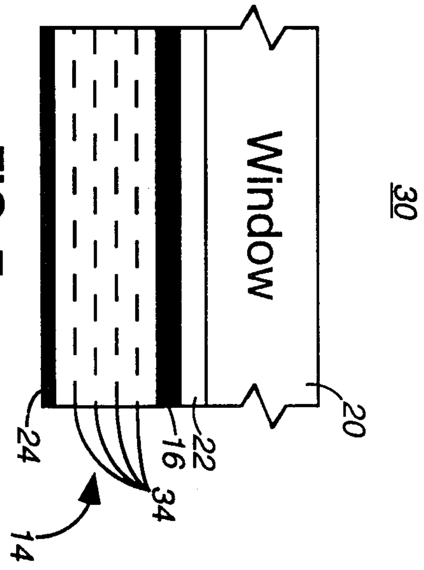

FIG. 7

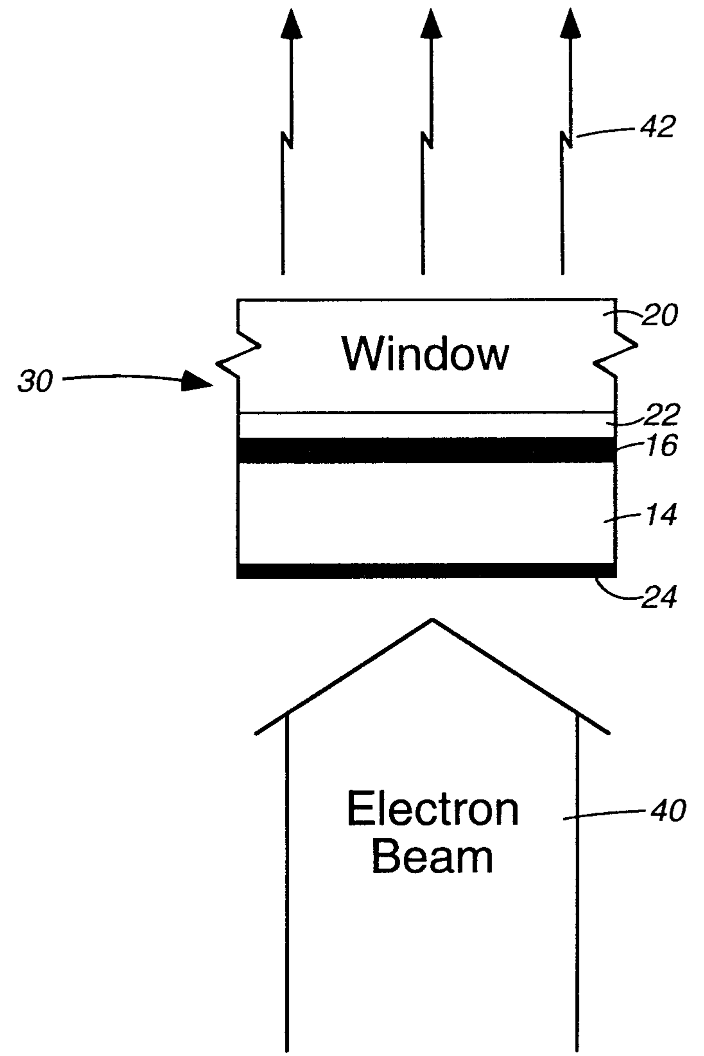

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/21241

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01S 3/18, 3/0959; B29D 11/00
US CL : 372/43, 74; 216/2, 24; 438/34, 69, 72, 689, 738, 751, 762, 763
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 372/43, 74; 216/2, 24; 438/34, 69, 72, 689, 738, 751, 762, 763

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,539,687 A (GORDON ET AL) 3 SEPTEMBER 1985, Column 5, Line 59 to Column 7, Line 49.	11-14, 26 --- 1-10, 15-25
X --- Y	US 4,881,236 A (BRUECK ET AL) 14 November 1989, Column 1, Line 50 to Column 5, Line 51.	26 --- 4, 5, 15, 16
X --- Y	US 5,131,002 A (MOORADIAN) 14 JULY 1992, Column 3, Lines 3-65.	26 --- 4, 5, 14, 15
X --- Y	US 5,313,483 A (KOZLOVSKY ET AL) 17 May 1994, Column 6, Line 18 to Column 7, Line 25.	26 --- 23, 24

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search

03 FEBRUARY 1998

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,317,583 A (NASIBOV ET AL) 31 May 1994, Column 3, Lines 16-50, Column 5, Line 53 to Column 6, Line 49.	26 ------- 22-24
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X --- Y	US 5,461,637 A (MOORADIAN ET AL) 24 October 1995, Column 1, Line 23 to Column 2, Line 68, Column 5, Line 1 to Column 6, Line 17.	26 -------- 4, 5, 6, 7, 15, 16
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Y	SINK. R.K. ET AL. Cleaved GaN Facets by Wafer Fusion of GaN to InP. Appl. Phys. Lett. April 1996. Vol 68. No. 15. Pages 2147-2149.	9

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

APS, STN, CAPLUS, FILE REG
search terms: semi conductor, semiconductor, laser, electron beam, e beam, pump, quantum well, indium gallium aluminum arsenide phosphide, InGaAlAsP, multiple isolated strained quantum, MISQW, transparent epoxy, epoxies, epoxide, epoxides, sapphire, gallium aluminum indium antimonide arsenide, GaAlInSbAs, mercury cadmium telluride, HgCdTe, cadmium zinc selenide sulfide, CdZnSeS, zinc cadmium sulfide, ZnCdS, gallium aluminum nitride, GaAlN