

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
15 March 2001 (15.03.2001)

PCT

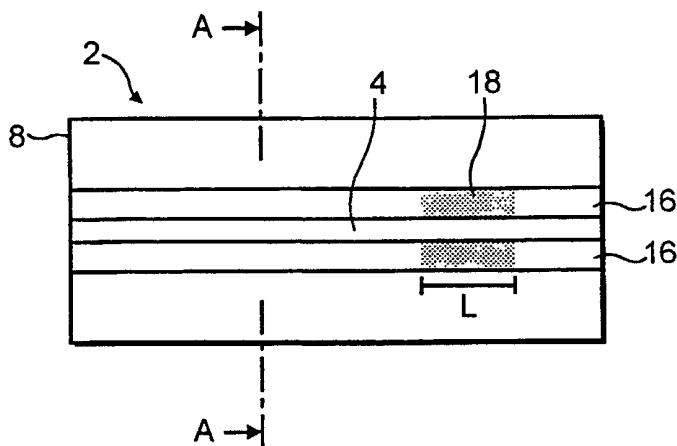
(10) International Publication Number
WO 01/18924 A1

- (51) International Patent Classification⁷: **H01S 5/22, 5/12**
- (21) International Application Number: PCT/GB00/03483
- (22) International Filing Date:
8 September 2000 (08.09.2000)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
9921445.4 8 September 1999 (08.09.1999) GB
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- (81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
- Published:**
— With international search report.
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.



WO 01/18924 A1

(54) Title: SEMICONDUCTOR LASER DIODE WITH A DISTRIBUTED REFLECTOR



(57) Abstract: There is disclosed a laser diode with a ridge waveguide (14), in which a distributed reflector takes the form of an array of holes (22) etched into the surface of the device on either side of the central waveguide.

SEMICONDUCTOR LASER DIODE WITH A DISTRIBUTED REFLECTOR

Laser devices are commonly used as light sources, and it is of particular interest to be able to obtain laser sources which have high quality spectral performance for data communication applications. It is of particular interest to be able to manufacture such devices in a relatively simple and low cost way, to achieve a robust device. In particular it is advantageous to achieve a device with a highly selective optical spectrum, that is, a device which produces a large amplitude peak at one specific wavelength of output light.

One type of laser device which can be used as such a source is a Distributed Feedback (DFB) laser, and the related Distributed Bragg Reflector (DBR) laser. However, conventional techniques for manufacturing such devices include regrowth steps, which make the manufacturing relatively expensive.

The paper "1.5 μ m wavelength DBR lasers consisting of $3\lambda/4$ -semiconductor and $3\lambda/4$ -groove buried with benzocyclobutene", M.M.Raj, J. Wiedmann, Y. Saka, H. Yasumoto and S. Arai. *Electronics Letter*, Vol.. 35, No. 16, pp. 1335-1337 describes a method of manufacturing deep etched (DBR) lasers. Since this technique involves etching into and across the active layer, the wave ceases to be guided within the etch, which means that these devices are likely to be inherently lossy.

The present invention relates to a laser device, with a ridge waveguide, with a distributed reflector on either side of the central ridge.

Since the light wave remains guided, this has the advantage that the device is relatively efficient.

Preferably, the reflector can be obtained by etching into the active layer on either side of the waveguide.

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This has the advantage that the reflector can be obtained without using additional regrowth steps.

Preferably, the reflector takes the form of a two-dimensional pattern. This allows efficient reflection, while allowing the reflector to be contained in a relatively short length of the device.

For a better understanding of the present invention, and to show how it may be put into effect, reference will now be made, by way of example, to the accompanying drawings, in which:-

Figure 1 is a plan view of a laser device in accordance with the invention.

Figure 2 is an enlarged schematic illustration of a region of Figure 1.

Figure 3 is a cross-sectional view through the device of Figure 1.

Figure 4 illustrates the room temperature (20°C) CW optical spectra at 60mA for (a) pre-etch non-AR coated and (b) post-etch AR coated conditions of the device of Figure 1.

Figure 5 illustrates the post-etch room temperature (20°C) CW L-I characteristics of the device of Figure 1.

Figure 6 illustrates the post-etch, room temperature (20°C) variation of lasing wavelength with CW bias current for the device of Figure 1.

Figure 1 is a top plan view of a laser device in accordance with the invention. The device 2 is an InGaAsP-InP laser, with a ridge-waveguide 4. The device consists of seven 0.8% compressively strained quantum wells, and operates at a centre wavelength of $\sim 1.29\mu\text{m}$. The laser is $350\mu\text{m}$ long, and acts as a Fabry-Perot (F-P) laser. It is cleaved on both end facets 6,8. The laser is bonded junction side up on a temperature-controlled submount (not shown) and the output can be connected via a lensed fibre. The back

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facet 6 is AR coated to 0.1%, in order to suppress the F-P modes.

Figure 3 is a cross-sectional view, taken on line A-A in Figure 1. As shown in Figure 3, the device has an active region 10 within the structure, with a silicon dioxide layer 12, having a metal layer 14 above it as the uppermost layers. The central ridge-waveguide has a width W of, for example, approximately $3\mu\text{m}$, with etched channels of width X of approximately $8\mu\text{m}$ on either side of the ridge waveguide.

In accordance with the preferred embodiment of the invention, a distributed reflector structure is provided on either side of the central ridge waveguide, leaving the waveguide itself untouched.

In this illustrated embodiment of the invention, the distributed reflectors take the form of an etched 2D-lattice grating 18. The grating 18 is etched into the bottom surfaces 20 of the channels 16, over a section of the cavity. This section has a length L of approximately $50\mu\text{m}$, and is located towards the back facet 6 of the device, for example approximately $50\mu\text{m}$ from the back facet.

Figure 2 is an enlarged view of the etched grating pattern in one of the channels 16. The array comprises a series of holes 22, etched through the top contact 14 to a depth which is comparable to the depth of the active region 10. In this illustrated embodiment, the holes 22 are arranged in a hexagonal array. That is, each hole away from the edge of the array is surrounded by six equally spaced holes. This separation a is of the order of $0.60\text{-}0.65\mu\text{m}$, and the holes have a radius r such that the radius-to-pitch ratio $r:a$ is 0.17, although it may be in the range of 0.17-0.33.

The grating pattern could also be a square array, or any pattern which provides a suitable reflector.

Preferably, the holes are etched to a depth which

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is very close to, or, more preferably, into the active region.

Advantageously, the holes can be obtained by post-processing using any available etching technique, for example, focused ion beam etching (FIBE) or reactive ion etching (RIE), without requiring any subsequent regrowth. This has the advantage that the device can be manufactured relatively simply and inexpensively.

This structure has the further advantage that the holes, which act as the reflectors, provide a high refractive index contrast ratio between the holes and the material of the device, of approximately 1:3.5.

In order to improve passivation, it is possible to fill in the etched holes with a suitable material, such as benzocyclobutene (BCB), which reduces this ratio to approximately 1.5:3.5. However, this ratio is sufficiently large that a highly selective characteristic can be obtained, over a short etched length.

The post-etch performance of the device is characterised in terms of the optical spectra. Measurements are taken at room temperature (20°C) under CW bias conditions. Figure 4a shows the pre-etch spectrum before AR coating at 60mA. This is indicative of a typical multi longitudinal mode F-P structure. Figure 4b illustrates clearly that, after etching, the device lases in a single longitudinal mode. Purely single mode operation is maintained over the entire operating current range up to over 3 times threshold. A typical SMSR value of >30dB is measured.

In order to investigate the stability of the lasing wavelength, the light current characteristics under CW bias conditions are measured at room temperature. Figure 5 shows a linear response above threshold, with no kinks evident, indicating that mode-hopping does not occur. A slope efficiency of 0.09 W/A

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is measured along with an output power of greater than 2.5mW at twice threshold current. At room temperature, a reduction in threshold current of 2mA was observed as a result of the etch.

5 Single mode operation is further evidenced in Figure 6, which shows the variation of peak wavelength with CW bias current at room temperature (20°C). From threshold up to 85mA, the lasing wavelength is found to vary linearly at 0.009nm/mA, indicating mode-hop-free
10 operation. The device spectra remain single mode over this range. Single mode emission is found to vary at the rate of 0.08nm/°C around room temperature.

 One possible use of the device of the invention is in an integrated device which has, say, four such laser
15 sources on a single device, with the distributed reflector structures of the four sources being different, such that the integrated device can selectively provide a source at any of four
wavelengths.

20 There is thus described a technique which allows manufacture of a single-contact, mode-hop-free single longitudinal mode laser operating CW at room temperature, and bit rates up to approximately 10 GHz, to be produced from a previously multi-mode Fabry-Perot
25 ridge-waveguide device.

30

CLAIMS:

1. An optical device, comprising a laser diode
5 having a ridge waveguide located above an active layer,
and having a distributed reflector located on either
side of the ridge waveguide.

2. An optical device as claimed in claim 1,
10 wherein the distributed reflector comprises a structure
in material above the active layer on either side of
the ridge waveguide.

3. An optical device as claimed in claim 1 or 2,
15 wherein the distributed reflector comprises a two-
dimensional structure in a plane parallel to the active
layer and extends to a depth comparable to that of the
active layer.

4. An optical device as claimed in claim 1, 2 or
3, wherein the distributed reflector comprises a two-
dimensional lattice when viewed from above the device.

5. An optical device as claimed in claim 1, 2 or
20 3, wherein the distributed reflector comprises a two-
dimensional lattice of holes etched into material above
the active layer on either side of the ridge waveguide.

6. An optical device as claimed in claim 5,
25 wherein the holes are arranged in a hexagonal array.

7. An optical device as claimed in claim 5,
wherein the holes are arranged in a square array.

8. An optical device, comprising a laser diode
30 having a ridge waveguide located above an active layer,
and having a distributed reflector in the form of a
lattice of individual elements, the elements being
arranged in a two-dimensional array.

9. An optical device as claimed in claim 8,
35 wherein the individual elements of the array are
arranged on either side of the central ridge waveguide.

10. An optical device as claimed in claim 8 or

9, wherein the distributed reflector comprises a structure in material above the active layer on either side of the ridge waveguide.

11. An optical device as claimed in claim 8, 9
5 or 10, wherein the distributed reflector comprises a two-dimensional structure in a plane parallel to the active layer and extends to a depth comparable to that of the active layer.

12. An optical device as claimed in claim 8, 9
10 or 10, wherein the distributed reflector comprises a two-dimensional lattice of holes etched into material above the active layer on either side of the ridge waveguide.

13. An optical device as claimed in claim 12,
15 wherein the holes are arranged in a hexagonal array.

14. An optical device as claimed in claim 12,
wherein the holes are arranged in a square array.

15. An optical device as claimed in claim 8,
20 wherein the individual elements of the array have a high refractive index contrast with the material of the device.

16. An edge emitting optical component, based on edge emitting laser diode structures, in which, single wavelength operation is achieved by design of a 2D-
25 lattice distributed reflector so that efficient optical emission (by lasing and/or spontaneous emission) is achieved depending on the electrical bias or biases applied to the device.

17. An optoelectronic component, as defined in
30 claim 16, wherein the modification of the structure may be achieved in manufacture through masking, e-beam lithography, X-ray or reactive ion etching (RIE) or other techniques or may be achieved through a post processing etching (such as focused ion beam etching
35 (FIBE)) or oxidation step or other process.

18. An optoelectronic component, as defined in

claim 16, wherein the structure may be an edge emitting Fabry-Perot lasing/amplifying/switching structure based on semiconductor/polymer technologies.

5 19. An optoelectronic component, as claimed in claim 16, wherein the lattice may be allowed to vary, both in terms of pattern, packing, overall shape and position.

10 20. An optoelectronic component, as claimed in claim 16, wherein the grating comprises holes that may be allowed to be vertical or at an angle and vary in size, spacing or shape.

15 21. An optoelectronic component, as claimed in claim 16, wherein the holes are defined as regions of different refractive index to that of the component structure.

22. An optoelectronic component, as claimed in claim 16, wherein the holes are defined as regions of different gain or loss to that of the component structure.

20 23. An optoelectronic component, as claimed in claim 16, wherein the holes are defined as regions of different refractive index and gain or loss to the component structure.

25 24. An optoelectronic component, as claimed in claim 16, wherein the grating may be introduced across the waveguide or waveguides on one or both sides.

30 25. An optoelectronic component, as claimed in claim 16, wherein the grating does not pierce the active region, partially pierce active region or possibly fully pierces the active region.

26. An optoelectronic component, as claimed in claim 16, wherein distributed gratings may be allowed within devices.

35 27. An optoelectronic component, as claimed in claim 16, wherein gratings may be allowed in pumped or un-pumped regions.

28. An optoelectronic component, as claimed in claim 26, wherein pumping may be of an electrical or optical nature.

5 29. An optoelectronic component, as claimed in claim 18, wherein any electrical contacts may be isolated.

30. An optoelectronic component, as claimed in claim 16, wherein the emission wavelength may be controlled/tuned.

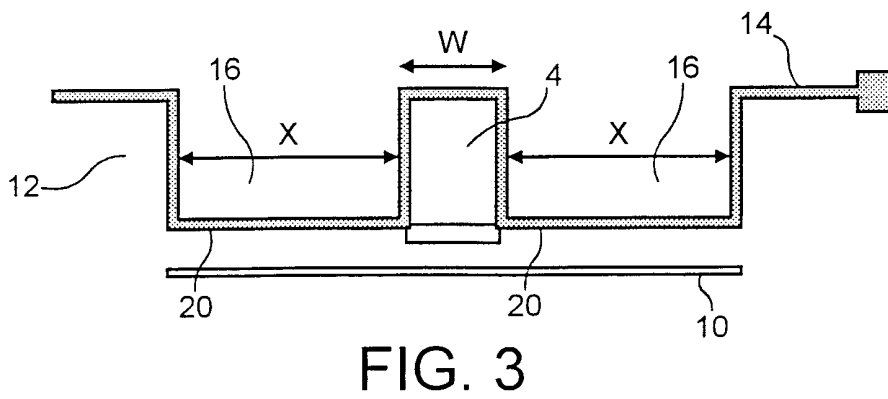
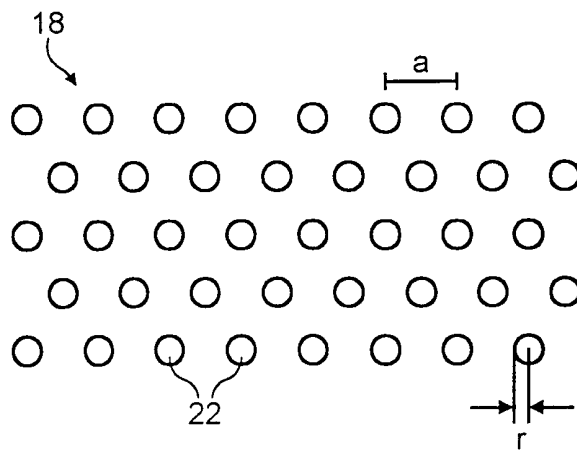
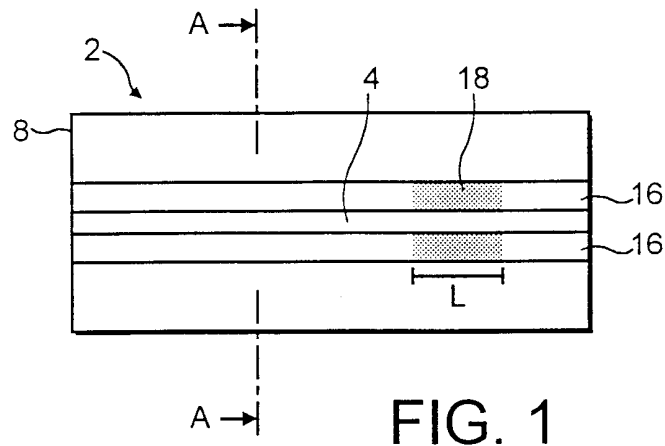
10 31. An optoelectronic component, as claimed in claim 16, wherein the device may be operated at high speed.

32. An optoelectronic component, as claimed in claim 16, which operates mode-hop-free.

15 33. An optoelectronic component, as claimed in claim 16, which is integrated with separate amplifying, absorbing or passive sections.

20 34. An optoelectronic component, as claimed in claim 33, where the amplifying or absorbing regions may have gain/loss modulated.

35. An optoelectronic component, as claimed in claim 16, which may be pulsed by gain switching, Q-switching or mode-locking techniques.



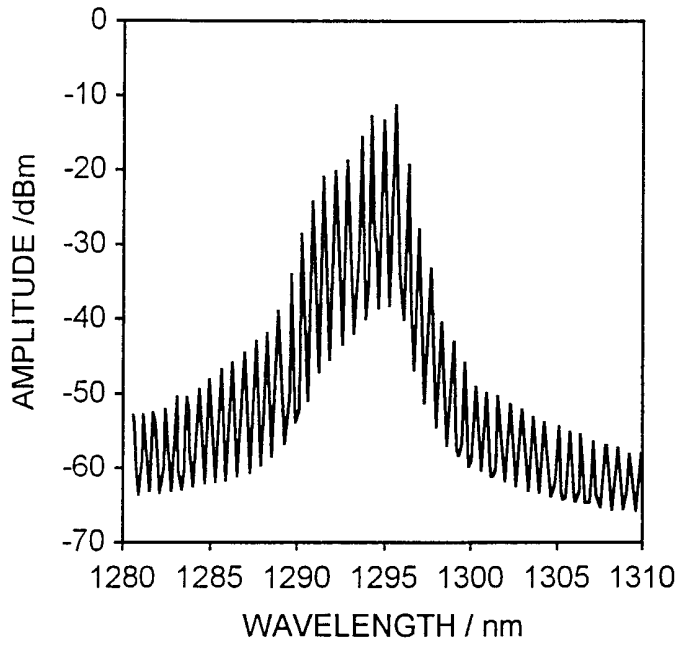


FIG. 4(a)

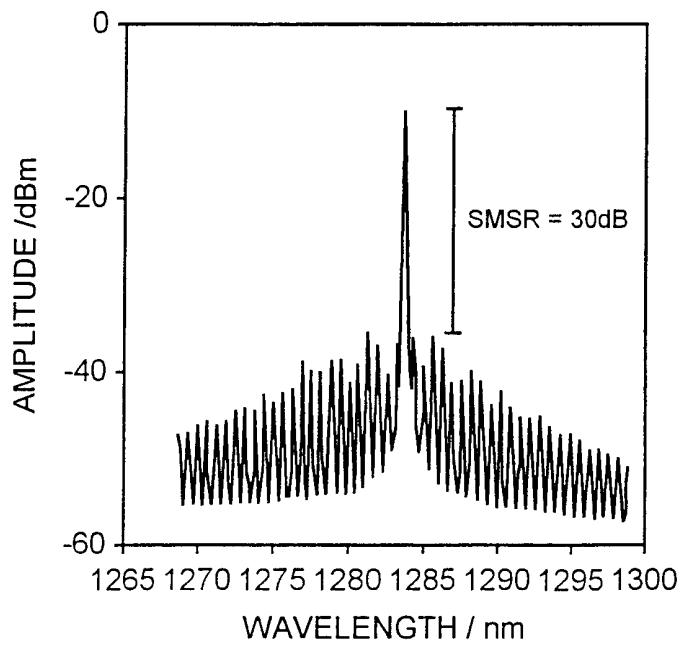


FIG. 4(b)

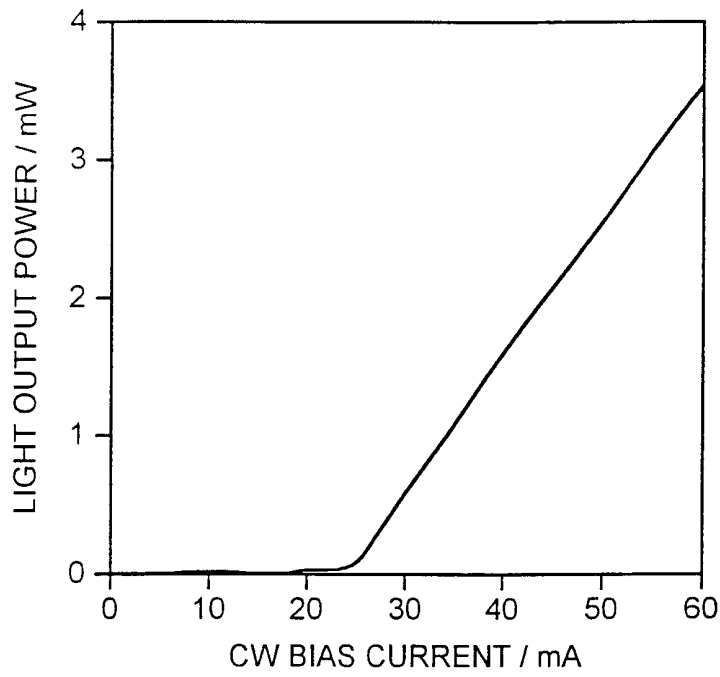


FIG. 5

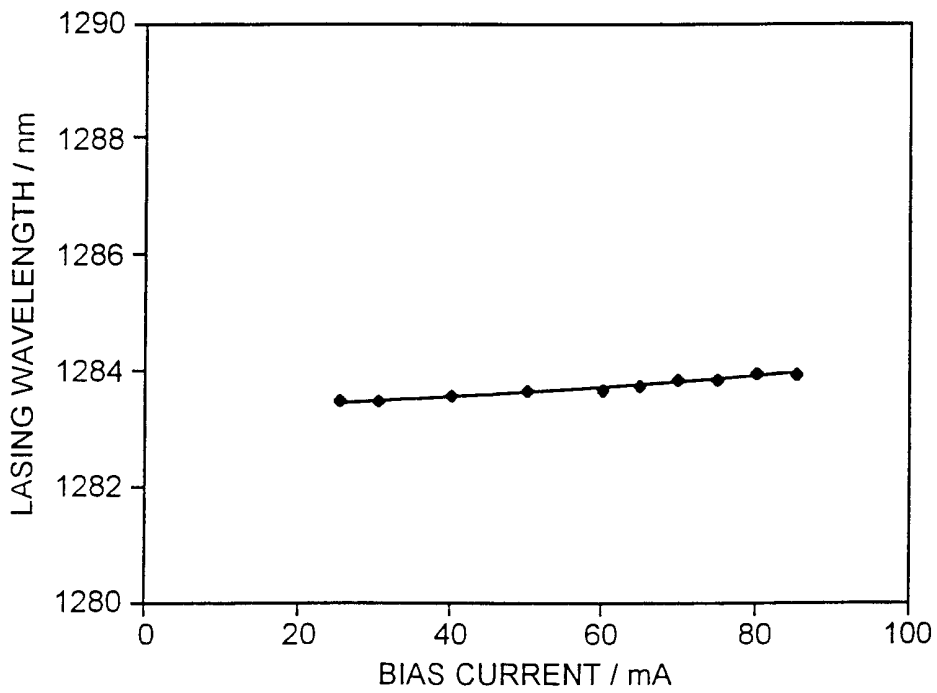


FIG. 6

INTERNATIONAL SEARCH REPORT

Inter. Jnal Application No

PCT/GB 00/03483

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>HAN H ET AL: "TWO-DIMENSIONAL RECTANGULAR LATTICE DISTRIBUTED FEEDBACK LASERS: A COUPLED-MODE ANALYSIS OF TE GUIDED MODES" IEEE JOURNAL OF QUANTUM ELECTRONICS,US,IEEE INC. NEW YORK, vol. 31, no. 11, 1 November 1995 (1995-11-01), pages 1947-1954, XP000541540 ISSN: 0018-9197 the whole document</p> <p style="text-align: center;">---</p>	1-4,16, 24-27
X	<p>MEIER M ET AL: "LASER ACTION FROM TWO-DIMENSIONAL DISTRIBUTED FEEDBACK IN PHOTONIC CRYSTALS" APPLIED PHYSICS LETTERS,US,AMERICAN INSTITUTE OF PHYSICS. NEW YORK, vol. 74, no. 1, 4 January 1999 (1999-01-04), pages 7-9, XP000804554 ISSN: 0003-6951 the whole document</p> <p style="text-align: center;">---</p>	16-23
A	<p style="text-align: center;">---</p>	1,5
X	<p>MILLER L M ET AL: "A DISTRIBUTED FEEDBACK RIDGE WAVEGUIDE QUANTUM WELL HETEROSTRUCTURE LASER" IEEE PHOTONICS TECHNOLOGY LETTERS,US,IEEE INC. NEW YORK, vol. 3, no. 1, 1991, pages 6-8, XP000202985 ISSN: 1041-1135 the whole document</p> <p style="text-align: center;">---</p>	1-5
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A	<p>US 5 684 817 A (HOUDRE ROMUALD ET AL) 4 November 1997 (1997-11-04) column 2, line 35 - line 60; figure 2C</p> <p style="text-align: center;">-----</p>	1,16

INTERNATIONAL SEARCH REPORT

Information on patent family members

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