

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
1 December 2005 (01.12.2005)

PCT

(10) International Publication Number
WO 2005/114307 A1

(51) International Patent Classification⁷: **G02F 1/015**,
H01L 27/00, H01S 5/026, H04B 10/17, G02F 1/21, 1/017,
H01L 21/265

(21) International Application Number:
PCT/CA2005/000781

(22) International Filing Date: 20 May 2005 (20.05.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/572,610 20 May 2004 (20.05.2004) US
0424253.3 2 November 2004 (02.11.2004) GB

(71) Applicant (for all designated States except US):
BOOKHAM TECHNOLOGY PLC [GB/GB]; Caswell,
Towcester Northamptonshire NN12 8EQ (GB).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **PROSYK, Kelvin**
[CA/CA]; 150 Guigues Avenue, Ottawa, Ontario K1N 5H9
(CA). **HAYSOM, Joan** [CA/CA]; 20 Hampton Avenue,
Ottawa, Ontario K1Y 0N2 (CA).

(74) Agent: **DERENYI, Eugene**; Stikeman Elliott LLP,
1600-50 O'Connor Street, Ottawa, Ontario K1P 6O2 (CA).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN,
CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI,
GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE,
KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA,
MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ,
OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL,
SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC,
VN, YU, ZA, ZM, ZW.

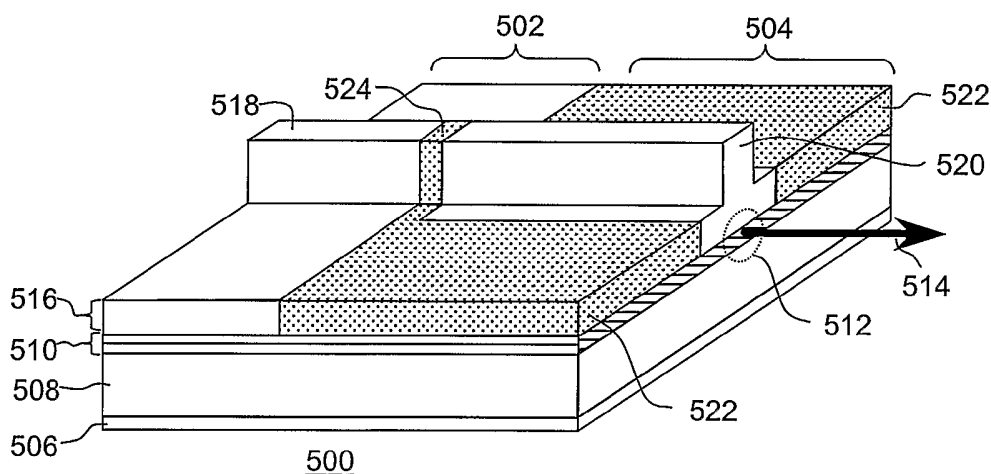
(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM,
ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),
European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI,
FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO,
SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN,
GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- with international search report
- before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments

[Continued on next page]

(54) Title: **LATERALLY IMPLANTED ELECTROABSORPTION MODULATED LASER**



(57) Abstract: A monolithically integrated electroabsorption modulated laser having a ridge waveguide structure, has lateral ion implantation. The integrated device has a laser section and a modulator section. The modulator section has ion implanted regions adjacent to the waveguide ridge. The implanted regions penetrate through the top cladding layer to reduce capacitance within the intrinsic active core of the reverse biased modulator and allow a shallow etched ridge waveguide structure to be used for the modulator. The device provides good optical coupling, efficient manufacturing, and good high power performance.



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.

LATERALLY IMPLANTED ELECTROABSORPTION MODULATED LASER

The present invention relates to the field of photonics and the construction of lasers and electroabsorption modulators, and more particularly with the construction of a monolithically integrated electroabsorption modulated laser.

Electroabsorption modulators (EAMs) provide a convenient and efficient way of modulating optical communications signals, especially those generated by laser sources. Combining a laser and an EAM into a monolithically integrated electroabsorption modulated laser (EML) can reduce manufacturing costs, assembly costs and footprint. An important consideration in monolithically integrating a laser and modulator on a single waveguide is that there must be good optical coupling between the two sections – there must be a good overlap between their optical modes.

The EAM section of EMLs known in the art generally to comprise deeply etched waveguides in one form or another. Etching deep is traditionally necessary in order to electrically disconnect the upper cladding layer from the rest of the chip in order to reduce capacitance of the EAM. In such devices, the top electrical contact to the modulator is only in contact with the upper region of the waveguide and thus the modulator has a low capacitance.

Traditional EMLs also generally adopt a buried heterostructure (BH) format for the deeply etched laser because it offers low threshold current and high efficiency. However, this generally requires the modulator to also be deeply etched and to use a buried waveguide format to avoid optical coupling problems between the laser and EAM sections. This format also suits the buried SI-InP style of EAM quite well, since the optical modes of the laser and EAM sections match laterally and the overgrowth used to bury them can be done in a single step for both. A drawback to the BH laser format, however, can be lower output power, poor reliability and more

complexity of manufacture when compared to a ridge wave guide (RWG) laser format.

Some traditional EMLs have EA sections that are deeply etched to the top of the waveguide core. For example, Noda et al., *Journal of Lightwave Technology*, Vol. LT-4, No. 10, October 1986, teaches an EAM section deeply etched to the top of the waveguide core to form a strip loaded EAM.

Other EMLs have EA sections deeply etched past the waveguide core, for example, Kawamura et al., *IEEE Journal of Quantum Electronics*, vol. QE-23, no. 6, June 1987, teaches monolithic integration of a distributed feedback laser with a deeply etched optical modulator. The integrated device is constructed using a hybrid growth technique wherein the laser is grown with liquid phase epitaxy in a BH configuration and the modulator is grown on the same substrate but with separate steps, using molecular beam epitaxy to produce a multiquantum well (MQW) modulator which is then deeply etched, so that the etching continues past the waveguide core. This device has a disadvantage of the BH configuration as well as requiring many discrete process steps to produce the laser and the modulator separately. Other possible disadvantages include limited modulation efficiency and less than ideal coupling between the laser and EAM, due to the hybrid growth technique.

Still other EMLs have EA sections deeply etched and then buried in semi-insulating (SI) InP. For example Tanaka et al., *Journal of Lightwave Technology*, vol. 8(9), p. 1357, 1990, teaches an EAM section deeply etched and then buried in SI-InP.

Aoki et al., *IEEE Journal of Quantum Electronics*, Vol. 29(6), p.2088, 1993, teaches a BH laser monolithically integrated with a BH MQW EAM. Here, both the laser and EAM are of a BH configuration and can benefit from common process steps in manufacture but still have the disadvantages of the BH configuration.

A ridge waveguide (RWG) laser could provide output power benefits over deep etched and BH lasers, but the shallow etch required for a RWG laser would be incompatible with the deep etch required for traditional EAMs. This incompatibility might possibly be overcome by a carefully managed shallow-to-deep etched transition region between the laser and the EAM to minimize back reflections into the laser. Disadvantages of this possible solution include increased costs for the extra processing steps of separate etches for the laser and the EAM, a deep etch and burial-overgrowth for the laser, and stringent manufacturing tolerances required for the transition region.

It would be advantageous to have an EML that could be operated at high output power. Accordingly, an improved monolithically integrated electroabsorption modulated laser (EML) remains highly desirable.

The invention aims to address these problems by providing an optoelectronic semiconductor device adapted for reverse-biased operation, comprising a semiconductor substrate, an active layer on the substrate, and a conductive layer on the active layer, the conductive layer having shallow etched regions, wherein said shallow etched regions are ion implanted such that the capacitance of the device is reduced.

The optoelectronic semiconductor device may comprise an electroabsorption modulator (EAM). The device may be monolithically integrated with a laser, which may be a distributed feedback laser or a tunable laser. Alternatively, or additionally the device may be monolithically integrated with a semiconductor optical amplifier (SOA). The laser and/or semiconductor optical amplifier may be in optical communication with the EAM. An active layer of the modulator may be optically aligned with an active layer of the laser and/or semiconductor optical amplifier. Said active layer may also be shared between the EAM and the laser and/or semiconductor optical amplifier.

The optoelectronic semiconductor device may comprise a laser section adapted to produce optical energy; and a modulator section wherein the conductive layer comprises a doped layer, said doped layer having a shallow etched ridge, said ridge defined by adjacent partially etched regions of said doped layer, said ridge adapted to guide said optical energy within the active layer, said modulator adapted to modulate said optical energy.

A second aspect of the invention provides an integrated optoelectronic semiconductor device comprising a semiconductor substrate, a ridge waveguide laser on the substrate, the laser having an active layer; and a shallow etched ridge modulator on the substrate, the modulator comprising an active layer adapted to be in optical communication with the semiconductor optical amplifier and a conductive layer on the active layer having ridge defined by shallow etched regions of the modulator adjacent the ridge and which are ion implanted such that the capacitance of device is reduced. The device may further comprise a semiconductor optical amplifier having an active layer in optical communication with the modulator and/or laser.

The second aspect of the invention may alternatively provide an integrated optoelectronic semiconductor device comprising a semiconductor substrate, a semiconductor optical amplifier on the substrate having an active layer; a shallow etched ridge modulator on the substrate, the modulator comprising an active layer adapted to be in optical communication with the semiconductor optical amplifier and a conductive layer on the active layer having ridge defined by shallow etched regions of the modulator adjacent the ridge and which are ion implanted such that the capacitance of device is reduced.

The ion implantation of the shallow etched regions adjacent the ridge may be such that it is substantially aligned with, spaced from or undercuts the ridge. The modulator may be an electroabsorption modulator and the laser may be a

distributed feedback laser or a tunable laser. The active layer of laser and/or SOA may be the same as the modulator. Alternatively the active layers may be formed differently using selective area growth or quantum well intermixing. The laser and/or SOA may be substantially the same as the modulator with respect to any of the ridge geometry, epitaxy, comprising a bulk active layer or comprising multiple quantum wells in the active layer.

A third aspect of the invention provides a method to form a reduced capacitance optoelectronic semiconductor device adapted for reverse-biased operation, with a substrate, and active layer thereon, and a conductive layer thereon, the conductive layer having partially etched regions that substantially cover the active layer, and further implanting ions into the partially etched regions. The ions may be implanted through the entire depth of the partially etched regions of the conductive layer, and may also be implanted through the active layer. Said ions may be hydrogen ions, or inert ions, that may be helium ions. A plurality of implanting steps, which may be three steps, may be used with different implant acceleration energy.

A fourth aspect of the invention provides an optoelectronic device comprising a semiconductor substrate, and active layer thereon, a doped layer thereon and having a ridge adapted to guide optical energy substantially in the active region that is defined by adjacent shallow etched regions of the doped layer, wherein at least a portion of said doped layer is adapted for reverse-biased operation and wherein the doped layers are ion implanted such that the capacitance of the device is reduced. The portion adapted for reverse-biased operation may comprise a modulator. The device may further comprise a laser and/or a semiconductor optical amplifier, which may be monolithically integrated with the modulator and may have a common epitaxial structure. The active layer of the laser and/or semiconductor optical amplifier may comprise a bulk active layer or a multiple quantum well structure. The laser may be a distributed feedback laser or a tunable laser. The

device may further comprise a curved waveguide and/or an anti-reflection coating at the output facet of the device, such that back reflection into the device is reduced.

By providing partially etched regions having ion implantation the capacitance of the device is reduced with respect to the capacitance of a device having no ion implantation regions. This gives the advantage that the device can be operated at high power, with higher reliability and higher performance than a device without such implantation. This advantage is shared by all embodiments of the invention.

Further features and advantages of the present invention will become apparent to those skilled in the art from the following detailed description of specific embodiments of the invention taken in combination with the appended drawings.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 is a schematic illustration showing a prior art deeply etched optoelectronic device;

FIG. 2 is a schematic illustration of a prior art buried heterostructure optoelectronic device;

FIG. 3 is a schematic illustration of a prior art shallow etched, weakly guided, optoelectronic device;

FIG. 4 is an schematic illustration of a shallow etched, weakly guided EAM with lateral ion implantation, according to an embodiment of the present invention; and

FIG. 5 is an isometric illustration of a monolithically integrated electroabsorption modulated laser with lateral ion implantation, according to an embodiment of the present invention.

It will be noted that, throughout the appended drawings, like features are identified by like reference numerals.

Generally, the present invention provides a monolithically integrated electroabsorption modulated laser wherein the modulator is of shallow etched ridge waveguide design which uses ion implantation of the etched upper cladding layer to reduce capacitance of the modulator.

FIG. 1 is a simplified illustration of a prior art deeply etched optoelectronic device 100. FIG. 1 can represent a semiconductor laser or an electroabsorption modulator (EAM). A laser or an EAM are constructed of similar materials, but would differ in design details and operation. The device of FIG. 1 will now be described as an EAM 100. The EAM 100 is deeply etched. It comprises a semiconductor substrate 101, an active layer 106, followed by an upper cladding layer 110 and a metal electrode 112. The optical mode 108 is approximately centered around the active layer 106 which functions as a vertical waveguide. The horizontal waveguide function is provided by the deeply etched ridge of material bounded by the vertical sides 114 which are created by deeply etching the top cladding layer 110, the active layer 106 and part of the lower cladding layer 102. An insulating layer 104 of polyimide for example may also be applied. The EAM 100 operates in a reverse biased mode by application of a negative voltage applied to the electrode 112, with respect to the substrate 101. Varying the bias voltage controls the amount of optical energy the active layer 106 will absorb, thus modulating the optical energy. In a well known doping pattern, the lower cladding layer 102 is n-doped and the upper cladding layer 110 is p-doped and the active layer 106 can be termed the intrinsic layer. In MQW EAMs, the active layer 106 can comprise multiple layers.

FIG. 2 is a simplified illustration of a prior art buried heterostructure (BH) optoelectronic device 200. The device of FIG. 2 will now be described as an EAM 200. The BH EAM 200 is also deeply etched. It comprises a semiconductor substrate

201, an active layer 206, followed by an upper cladding layer 210 and a metal electrode 212. The optical mode 208 is approximately centered around the active layer 206 which functions as a vertical waveguide. The horizontal waveguide function is provided by the deeply etched ridge of material bounded by the vertical sides 214 which are created by deeply etching the top cladding layer 210, the active layer 206 and part of the lower cladding layer 202. In this device, the deeply etched ridge is buried in a semiconductor material 204.

FIG. 3 is a simplified illustration of a prior art shallow etched, weakly guided, optoelectronic device 300. The device of FIG. 3 will now be described as an EAM 300. The EAM 300 is shallow etched. It comprises a semiconductor substrate 301, an active layer 306, followed by an upper cladding layer 310 and a metal electrode 312. The optical mode 308 is approximately centered around the active layer 306 which functions as a vertical waveguide. A weakly guided horizontal waveguide function is provided by the shallow etched ridge of material bounded by the vertical sides 314 which are created by shallow etching part of the top cladding layer 310 only. An insulating layer 304 of polyimide for example may also be applied. The optical mode 308 is substantially below the bottom of the etch. In EAMs constructed in this manner, there is no electrical confinement in the upper cladding layer 310 and therefore the modulator's electrode 312 electrically connects with the remaining upper cladding layers 310 beside the waveguide thus creating a substantial capacitance across the active layer 306. This can cause a considerable problem to high frequency drive signals applied to the electrode 312 of the modulator 300.

The present invention allows a useful EAM to be constructed as a shallow etched device, by providing electrical confinement in the upper cladding by the use of ion implantation. This EAM is well adapted for monolithic integration with a shallow etched ridge waveguide laser and/or semiconductor optical amplifier (SOA). With reference to FIG. 4, an embodiment of the present invention is illustrated in simplified form as a shallow etched, weakly guided EAM 400. EAM 400 comprises a

semiconductor substrate 401, an active layer 406, followed by an upper cladding layer 410 and a metal electrode 412. The optical mode 408 is approximately centered around the active layer 406 which functions as a vertical waveguide. A weakly guided horizontal waveguide function is provided by the shallow etched ridge of material bounded by the vertical sides 414 which are created by shallow etching part of the top cladding layer 410 only, such that the optical mode 408 is substantially below the bottom of the etch. In this case, electrical confinement is provided by ion implanted regions 416, thus greatly reducing the otherwise substantial capacitance of a shallow etched EAM configuration. In one embodiment, an insulating layer 404 of polyimide for example may also be applied. It is important that the implanted regions 416 penetrate through the top cladding layer 410. The implanted regions 416 are shown here also penetrating the active region 406 and partially into the lower cladding region 402, but this is not required. In the embodiment shown in Fig. 4, the inside edges of the regions 416 have a jagged profile.

Ion implantation is known in the art, but for very different purposes. For example Q. Z. Liu et al., *Journal of Electronic Materials*, Vol. 24(8), p.991, 1995, discloses a processing technique to fabricate planar InGaAsP/InP electroabsorption waveguide modulators. Lateral ion implantation is used on a strain guided device specifically to confine the electric field between adjacent modulators.

The present invention offers advantages of using a shallow etched waveguide for an EAM, such as simplicity of design and compatibility with shallow etched waveguide lasers and/or SOAs, thereby permitting good optical coupling between such optical elements and the modulator. Reliability is also improved because fewer regrowth surfaces are required and typically lossy burying materials are not required, as compared to deeply etched and BH devices. Another advantage is that heat dissipation for shallow etched waveguides is very good.

FIG. 5 shows a simplified isometric illustration of another embodiment of the present invention. A shallow etched monolithically integrated electroabsorption modulated laser (EML) 500 comprises a laser section 502 and a modulator section 504, fabricated on a common substrate 506 and a common lower cladding layer 508. An intrinsic active layer 510 provides a vertical waveguide for optical energy created in the laser section 502. A weakly guided horizontal waveguide function is provided by shallow etched ridge 518 in the laser section 502 and by shallow etched ridge 520 in the modulator section 504. Ridge 518 and ridge 520 can be etched from the upper cladding layer 516 in a single operation during construction, ensuring alignment and good optical coupling between the laser section and the modulator section. The optical mode 512 is approximately centered around the active layer 510 and below the ridge 518 and ridge 520. The optical energy exiting the EML 500 is represented here by arrow 514. The active layer 510 is illustrated as a uniform structure having a common epitaxial structure. The active layer 510 can optionally comprise multiple quantum wells. In another embodiment, a section of the active layer 510 within the laser section 502 can have a different composition than the section of the active layer 510 within the modulator section 504. For example, an enhanced selective area growth technique can use a single growth for both sections, but one of the sections can then be enhanced using an oxide mask to form a different composition. In a further example, the different compositions can be formed by using quantum well intermixing.

Within the modulator section 504 of the EML 500, areas of the upper cladding layer 516 adjacent to the ridge 520 are implanted with ions to create ion implanted regions 522. This serves to dramatically reduce capacitance within active layer 510 of the modulator section 504, and allow the use of a shallow etched ridge waveguide design for an electroabsorption modulator. This, in turn allows the modulator to be easily integrated with a shallow etched ridge waveguide laser. In Fig. 5, the boundaries of the regions 522 have been simplified for illustration purposes and are

shown as being straight. In the embodiment of Fig. 5, the regions 522 are spaced from the ridge 520. The separation of the regions 522 from the ridge 520 is minimized to minimize the capacitance of the EML 500. In the preferred embodiment, the regions 522 are spaced as close to the ridge 520 as possible without significantly interfering with the optical mode, and more preferably, the regions 522 are spaced from the sides of the ridge 520 by a maximum of about 1 μm and even more preferably, by a maximum of 0.5 μm .

In another embodiment, the regions 522 undercut the ridge 520. In a further embodiment, the regions 522 are substantially aligned with the ridges 520.

The ion implantation of regions 522 can be performed vertically into the top of the EML 500 using processes well known in the art, by applying a silicon dioxide mask symmetrically aligned with the ridge 520. The implantation mask is typically wider than the ridge 520, so that the implantation, which tends to undercut the mask, does not significantly enter the waveguide, which could cause optical losses. The implantation step can be performed either before or after the ridge etching step. Ion implantation is performed in one or more steps using different implant acceleration energies to control the implantation depth and the uniformity of the ion implantation. Ion implantation is done with inert ions such as hydrogen or helium ions.

The laser section 502 operates in a forward biased mode and the modulator section 504 operates in a reverse biased mode, thus the two sections require electrical isolation. A section 524 of the continuous ridge 518, 524, 520 is also implanted with ions, to provide the required electrical isolation. In other embodiments, the electrical isolation can be provided by a physical gap between ridge 518 of the laser section and ridge 520 of the modulator section. The laser may be a distributed feedback laser or a tunable laser. For simplicity of illustration, electrical contact

pads, bonding pads, laser grating and other details of modulator and laser construction have been omitted from FIG. 5.

The scope of the device of the present invention further includes a shallow etched monolithically integrated modulator and semiconductor optical amplifier (SOA). The structure of such a device may be substantially similar to that of the EML illustrated in Fig. 5. Further the order of the modulator and SOA may be reversed, with respect to the light direction 514.

Fig. 6 shows a simplified isometric illustration of an embodiment of the present invention in which a laser section 502, SOA section 602 and modulator section 504 are fabricated on a common substrate 506 and a common lower cladding layer 508. Like numbers in Fig. 6 and Fig. 5 are used to show like features. The SOA section 602 is driven by a different bias from both the laser 502 and modulator sections 504, thus the three sections require electrical insulation. Two sections 524, 624 of the continuous ridge 518, 524, 618, 624, 520 is also implanted with ions, to provide the required electrical isolation. In other embodiments the electrical isolation can be provided by a physical gap between different sections of the ridge. For simplicity details of device construction have been omitted from Fig. 6. Other orderings of the different sections of the device are possible such as laser 502, modulator 504 and SOA sections 602.

Embodiments of the present invention may also include optical trap layers or large optical superlattices to control the location of optical mode within the device, as are described in United States Patent No. 6,724,795 and the PCT patent application published as WO2004/084366.

Embodiments of the present invention may also include features to reduce reflections from the facets of ridge waveguide, such as curved waveguides or anti-reflection coatings.

Using the same etch for the laser and/or SOA and modulator removes one or more of the etch steps and consequently several processing steps. Also avoiding the need to bury the structure avoids several other processing steps.

The illustrated embodiments describe an electroabsorption type modulator. The present invention however, applies to other types of modulators such as Mach Zehnder modulators, a concatenated series of Mach-Zehnder modulators, phase modulators or electroabsorption-like devices such as self-electro-optic effect devices (SEED).

The embodiment(s) of the invention described above is(are) intended to be exemplary only. The scope of the invention is therefore intended to be limited solely by the scope of the appended claims.

CLAIMS:

1. An optoelectronic semiconductor device adapted for reverse-biased operation, comprising:

a semiconductor substrate;

an active layer on the substrate; and

a conductive layer on the active layer, having shallow etched regions, wherein said shallow etched regions define a ridge waveguide, and wherein at least a portion of said shallow etched regions is ion implanted such that the capacitance of the device is reduced.
2. An optoelectronic semiconductor device as claimed in claim 1, comprising an electroabsorption modulator.
3. An optoelectronic semiconductor device as claimed in claim 2, wherein the semiconductor device further comprises a monolithically integrated laser, such that the electroabsorption modulator is in optical communication with the laser.
4. An optoelectronic semiconductor device as claimed in claims 2 or 3, wherein the semiconductor device further comprises a monolithically integrated semiconductor optical amplifier, such that the electroabsorption modulator is in optical communication with the laser and/or the semiconductor optical amplifier.
5. An optoelectronic semiconductor device as claimed in claims 3 or 4, wherein the active layer of the modulator is optically aligned with an active layer of the laser and/or the semiconductor optical amplifier.

6. An optoelectronic semiconductor device as claimed in claim 5, wherein the active layer of the modulator is shared by the laser and/or semiconductor optical amplifier.
7. An optoelectronic semiconductor device as claimed in claims 3, 5 or 6, wherein the laser is a distributed feedback laser.
8. An optoelectronic semiconductor device as claimed in claim 3, wherein; the laser section is adapted to produce optical energy; and the modulator section wherein the conductive layer comprises a doped layer, said doped layer having a shallow etched ridge, said ridge defined by adjacent partially etched regions of said doped layer, said ridge adapted to guide said optical energy within the active layer, said modulator adapted to modulate said optical energy.
9. An integrated optoelectronic semiconductor device comprising:
 - a semiconductor substrate;
 - a ridge waveguide laser on the substrate, the laser having an active layer; and
 - a shallow etched ridge modulator on the substrate, the modulator comprising:
 - an active layer adapted to accept optical energy from the laser; and
 - a conductive layer on the active layer, the conductive layer having a ridge defined by shallow etched regions of the modulator adjacent the ridge, wherein the shallow etched regions adjacent the ridge are ion implanted creating implanted regions such that the capacitance of the device is reduced.
10. An integrated optoelectronic semiconductor device comprising:

a semiconductor substrate;

a semiconductor optical amplifier on the substrate, the semiconductor optical amplifier having an active layer; and

a shallow etched ridge modulator on the substrate, the modulator comprising:

an active layer adapted to be in optical communication with the semiconductor optical amplifier; and

a conductive layer on the active layer, the conductive layer having a ridge defined by shallow etched regions of the modulator adjacent the ridge, the shallow etched regions adjacent the ridge are ion implanted creating implanted regions such that the capacitance of the device is reduced.

11. An integrated optoelectronic semiconductor device as claimed in claim 9 further comprising:

a semiconductor optical amplifier on the substrate, the semiconductor optical amplifier having an active layer in optical communication with the modulator and/or laser
12. An integrated optoelectronic semiconductor device as claimed in any of claims 9 to 11, wherein the implanted regions are substantially aligned with the sides of the ridge.
13. An integrated optoelectronic semiconductor device as claimed in any of claims 9 to 11, wherein the implanted regions are spaced from the ridge.
14. An integrated optoelectronic semiconductor device as claimed in any of claims 9 to 11, wherein the implanted regions undercut the ridge.

15. An integrated optoelectronic semiconductor device as claimed in any of claims 9 to 14, wherein the modulator is an electroabsorption modulator.
16. An integrated optoelectronic semiconductor device as claimed in any of claims 9 or 11 to 15, wherein the laser is a distributed feedback laser or a tunable laser.
17. An integrated optoelectronic semiconductor device as claimed in any of claims 9 to 16, wherein the active layer of the laser and/or semiconductor optical amplifier is substantially the same as the active layer of the modulator.
18. An integrated optoelectronic semiconductor device as claimed in any of claims 9 to 17, wherein the ridge waveguide geometry of the laser and/or semiconductor optical amplifier is substantially the same as the ridge waveguide geometry of the modulator.
19. An integrated optoelectronic semiconductor device as claimed in any of claims 9 to 18, wherein the epitaxial structure of the laser and/or semiconductor optical amplifier is substantially the same as the epitaxial structure of the modulator.
20. An integrated optoelectronic semiconductor device as claimed in any of claims 9 to 19, wherein the active layer of the laser and/or semiconductor optical amplifier comprises a bulk active layer.
21. An integrated optoelectronic semiconductor device as claimed in any of claims 9 to 19, wherein the active layer of the laser and/or semiconductor optical amplifier of the laser comprises a multiple quantum well structure.
22. A method of reducing capacitance of an optoelectronic semiconductor device adapted for reverse-biased operation, the semiconductor device having a semiconductor substrate, an active layer on the substrate and a conductive

layer on the active layer, the conductive layer having shallow etched regions, wherein the shallow etched regions define a ridge waveguide, the method comprising a step of implanting ions in at least a portion of the shallow etched regions.

23. A method of reducing capacitance of a semiconductor device as claimed in claim 22, wherein the ions are implanted through the entire depth of the etched regions of the conductive layer.
24. A method of reducing capacitance of a semiconductor device as claimed in claim 23, wherein the ions are further implanted through the active layer.
25. A method of reducing capacitance of a semiconductor device as claimed in any of claims 22 to 24, wherein the ions are inert ions.
26. A method of reducing capacitance of a semiconductor device as claimed in any of claims 22 to 24, wherein the ions are hydrogen ions.
27. A method of reducing capacitance of a semiconductor device as claimed in any of claims 22 to 25, wherein the ions are helium ions.
28. A method of reducing capacitance of a semiconductor device as claimed in any of claims 21 to 27, the method comprising a plurality of implanting steps, each having a different implant acceleration energy.
29. A method of reducing capacitance of a semiconductor device as claimed in claim 28, the method comprising three consecutive implanting steps of increasing implant acceleration energy.
30. An optoelectronic device, the optoelectronic device comprising:

a semiconductor substrate;

an active layer on the substrate; and

a doped layer on the active layer, the doped layer having a ridge adapted to guide optical energy in the active layer, said ridge defined by adjacent shallow etched regions of the doped layer, wherein at least a portion of said doped layer is adapted for reverse-biased operation and the shallow etched regions within said at least a portion of said doped layer are ion implanted such that the capacitance of the device is reduced.

31. An optoelectronic device as claimed in claim 30, wherein said portion adapted for reverse-biased operation, comprises an electroabsorption modulator.
32. An optoelectronic device as claimed in claims 30 or 31, wherein said optoelectronic device further comprises a laser.
33. An optoelectronic device as claimed in any of claims 30 to 32, wherein said optoelectronic device further comprises a semiconductor optical amplifier.
34. An optoelectronic device as claimed in claims 32 or 33, wherein said modulator and said laser and/or semiconductor optical amplifier are monolithically integrated.
35. An optoelectronic device as claimed in any of claims 32 to 34, wherein the laser is a distributed feedback laser.
36. An optoelectronic device as claimed in any of claims 32 to 34, wherein the laser is a tunable laser.
37. An optoelectronic device as claimed in any of claims 32 to 36, wherein the active layer of said laser and/or semiconductor optical amplifier and the active layer of said modulator have a common epitaxial structure.

38. An optoelectronic device as claimed in any of claims 32 to 37, wherein the active layer of said laser and/or semiconductor optical amplifier comprises a bulk active layer.
39. An optoelectronic device as claimed in any of claims 32 to 37, wherein the active layer of said laser and/or semiconductor optical amplifier comprises a multiple quantum well structure.
40. An optoelectronic device as claimed in any of claims 30 to 39, in which the output of the device comprises a curved waveguide adjoining the output facet of the device and/or an anti-reflection coating on the output facet.
41. An optoelectronic device as claimed in any of claims 30 or 32 to 40, wherein said portion adapted for reverse-biased operation comprises any of a Mach-Zehnder modulator, a concatenated series of Mach-Zehnder modulators, a phase modulator, or a self-electro-optic effect device.
42. An integrated optoelectrical semiconductor device as claimed in claim 13 wherein the implanted regions are spaced from the ridge to minimize the capacitance of the device.
43. An integrated optoelectrical semiconductor device as claimed in claim 42 wherein the implanted regions are spaced from the ridge by a maximum of about 1 μm .
44. An integrated optoelectrical semiconductor device as claimed in claim 42 wherein the implanted regions are spaced from the ridge by a maximum of about 0.5 μm .

1 / 3

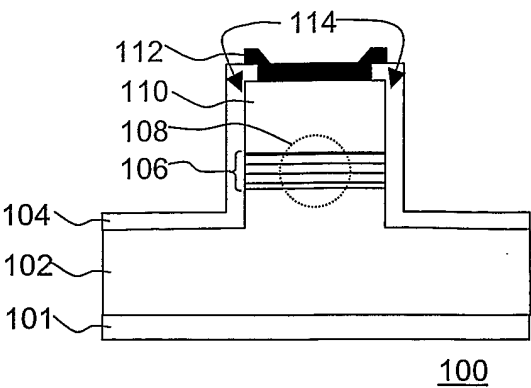


Figure 1
(Prior Art)

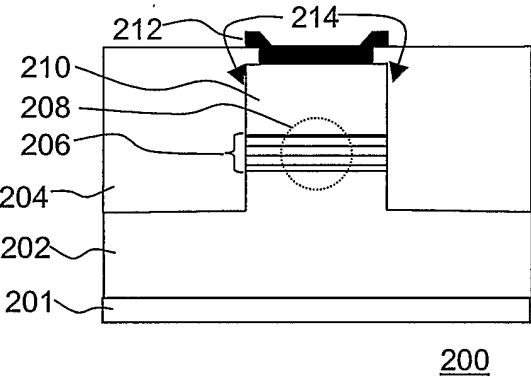


Figure 2
(Prior Art)

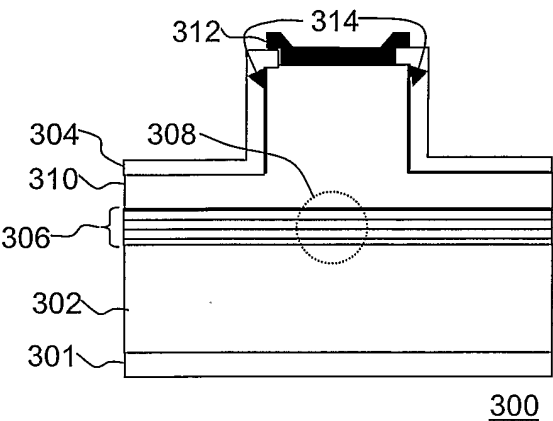


Figure 3
(Prior Art)

2 / 3

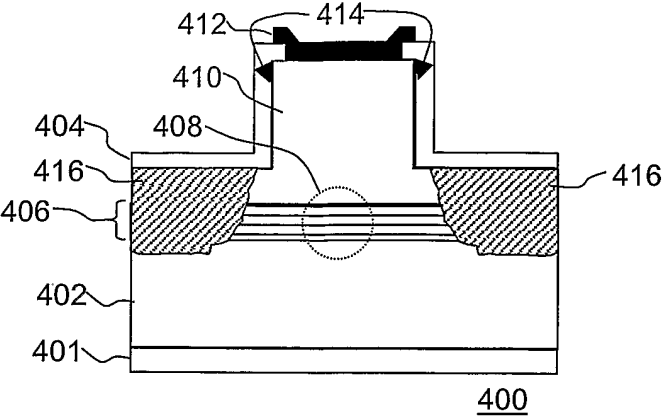


Figure 4

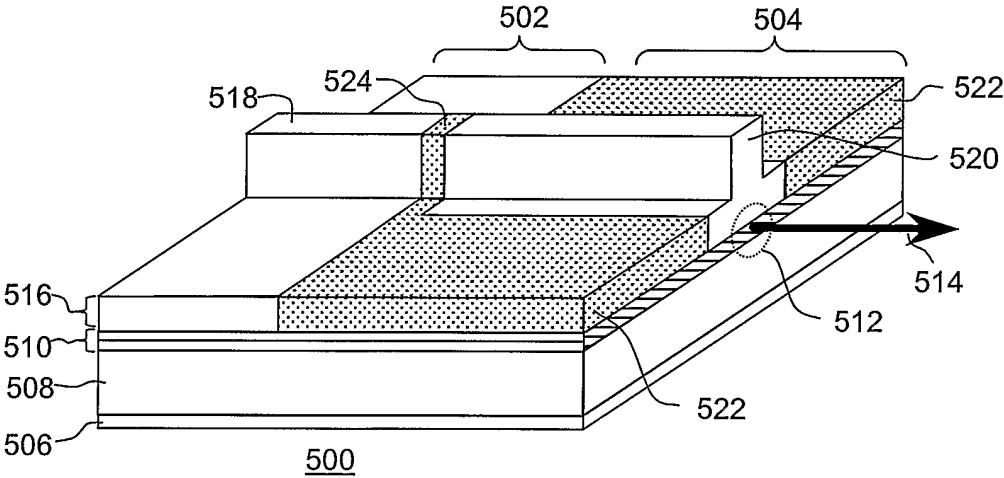


Figure 5

3 / 3

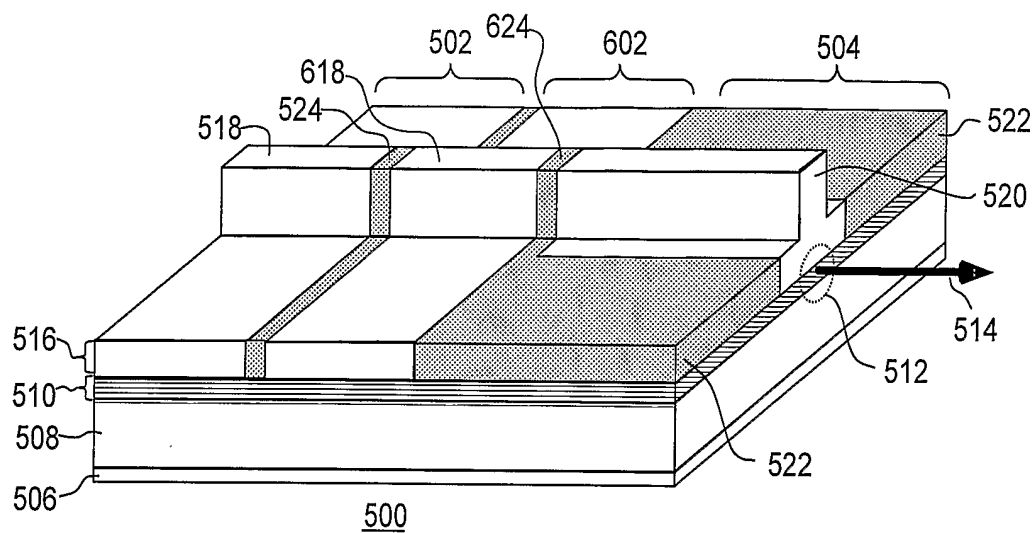


Figure 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2005/000781

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7): G02F 1/015, H01L 27/00, H01S 5/026, H04B 10/17, G02F 1/21, G02F 1/017, H01L 21/265

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)
IPC (7): G02F, H01L

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

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

Databases searched: Delphion, Pluspat, Google, Canadian Patent Database (CPD)

Keywords: electroabsorption modulator, ion implantation, capacitor, laser, ridge waveguide, etching, well

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6 162 655 19.Dec., 2000 (19.12.2000), ** Abstract, Fig. 1-18, col.2, line 25 to line 49, col. 3, line 45 to col. 4 line 58, col. 6, line 15- col. 6, line 64**	1, 3-6, 8, 9, 32, 37
Y	JP 03222387 (A2) 1.Oct., 1991 (01.10.1991) ** Abstract and whole document**	1, 2, 8, 30, 36-39
Y	JP 06053596 (A2) 25 Feb.1994 (25.02.1994) ** Abstract and whole document**	2-7, 31-39
A	EP 0 653 822(B1) 17.May, 1998 (17.05.1995) **whole document**	1-44
A	US 2004/0027634 12.Feb., 2004 (12.02.2004) **whole document**	1-44
A	US 2003/0142895 31.July, 2003 (31.07.2003) **whole document**	1-44

☒ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents :	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
30 August 2005 (30-08-2005)

Date of mailing of the international search report
19 September 2005 (19-09-2005)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 001(819)953-2476

Authorized officer
Karen Oprea (819) 934-2668

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2005/000781

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/0043448 6 Mar. 2003 (06.03.2003) **whole document**	1-44
A	2003/0025976 6 Feb., 2003 (06.02.2003) **whole document**	1-44
A	6 335 819 1 Jan., 2002 (01.01.2002) **whole document**	1-44

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2005/000781

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US6162655	19-12-2000	US6162655 A	19-12-2000
JP03222387	01-10-1991		
JP06053596	25-02-1994		
EP0653822	17-05-1995	DE69410214D D1 DE69410214T T2 JP3227322B2 B2 US5432123 A	18-06-1998 03-12-1998 12-11-2001 11-07-1995
US2004027634	12-02-2004	US6661556 B2 US6844954 B2	09-12-2003 18-01-2005
US2003142895	12-02-2004	US6804421 B2 US6862376 B2	12-10-2004 01-03-2005
US2003043448	31-07-2003	US6661556 B2 US6844954 B2	09-12-2003 18-01-2005
US2003025976	06-02-2003	US6665105 B2	16-12-2003
US6335819	01-01-2002	US6335819 B1	01-01-2002