

DISTRIBUTED FEEDBACK AND DISTRIBUTED BRAGG REFLECTOR SEMICONDUCTOR LASERS

FIELD OF INVENTION

The present invention relates broadly to a Distributed Feedback (DFB) laser structure, to a method of fabricating a DFB laser structure, to a Distributed Bragg Reflector (DBR) laser structure, and to a method of forming a DBR laser structure.

BACKGROUND

DFB and DBR lasers are widely used as light sources in optical fibre communication, as optical pumps and for generating coherent optical pulses.

A DFB and a DBR laser typically operate at a single emission wavelength with a narrow linewidth. In conventional DFB and DBR lasers, an optical resonator is defined through an index grating, which is constructed e.g. by a periodic corrugation of different semiconductor materials with different refractive indices in the laser beam guiding direction. Since cleaved mirrors are not prerequisite, DFB and DBR lasers are the preferred types of light sources in photonics integration applications and in materials for which it is difficult to construct cleaved facets.

Resonance in the optical cavity in the DFB and DBR lasers is achieved through feedback from the index grating. The grating strength that affects light propagation in a waveguide is described by the coupling coefficient, κ , which is related to the grating shape, the corrugation depth, the distance of the grating from the active region and the refractive index difference between the two materials forming the grating.

In a conventional index coupled DFB or DBR laser, the grating is typically formed by a periodic arrangement of semiconductor materials with different refractive indices. The materials used to form the grating can be, for example,

InP with InGaAsP, GaAs with AlGaAs, InGaAsSb with InP, etc. The refractive index difference between the two materials is small and usually less than 10% comparatively. The resulting coupling coefficient thus requires that a long grating length be used to achieve sufficient reflectivity and a wavelength selectively for a laser cavity.

In a conventional DBR laser, the distributed Bragg reflector is separated from the laser active region. The reflector region has a band gap energy larger than the laser wavelength so as to avoid any absorption of the laser light. Usually, portions of an active region layer, which may comprise quantum wells, are totally etched away and the gaps then refilled with higher band gap energy materials by re-growth or the quantum wells are grown to a higher energy level by a selective growth method.

However, etching and regrowth can introduce extra phases and intensity loss to the propagating light. Although etching and regrowth can be avoided through the use of quantum well intermixing, precise alignment of e.g. a SiO₂ mask used is often needed, which increases complexity in the fabrication process.

A feature of conventional index coupled DFB lasers is the existence of two longitudinal modes, the left and right Bragg modes, across a laser stop band having the same threshold gain. This results in poor single mode operation.

A quarter-wave phase shift may be introduced at the centre of the laser cavity at one of the two degenerate modes. However, the yield of single mode lasing is low due to the random facet phase by cleaving and any small changes in mode reflectivity. Moreover, the spatial hole burning effect greatly deteriorates the side mode suppression ratio and the output power of such lasers at high current injection levels.

Another approach to overcome the mode degeneracy is to introduce a gain coupling mechanism into DFB lasers. In complex coupled DFB lasers with both index and gain coupling, a periodic optical gain or loss modulation coupled with conventional index corrugation can effectively overcome the mode degeneracy between the two Bragg modes around the stop band, thus providing

a stable single mode operation. With the introduction of even a small amount of gain or loss coupling, the dynamic single mode yield of complex coupled DFB lasers increases drastically.

Gain or loss coupling effectively provides lasing predominantly on a preferred and fixed Bragg mode among the two original degenerate modes regardless of the random distribution of unknown laser facet phases. In the case of in-phase gain coupling, the grating period with the higher index region has a higher optical gain. The laser will lase at the right Bragg mode with a longer wavelength than the Bragg mode. On the other hand, in the case of anti-phase gain coupling, the grating period with a higher index region experiences a higher optical loss. The laser will lase at the left Bragg mode with a shorter wavelength than the Bragg wavelength.

Complex coupled DFB lasers have been studied intensively worldwide. It has been demonstrated that they have high single mode yield, less sensitivity to external reflection, high modulation bandwidth and reduced wavelength chirp. However, complex coupled DFB lasers are mostly realised by etching away part of the active region quantum wells and then filling the gaps with another semiconductor material with a higher band gap by re-growth. This requires the etching to be controlled to several nanometer precision and a very deliberate etching process to avoid any damage introduced into the active region. The current flow through the non-quantum well region will also reduce the quantum efficiency. Although current blocking layers can be introduced into the etched region to reduce this problem of reduced quantum efficiency, this increases the complexity of the re-growth steps.

SUMMARY

In accordance with a first aspect of the present invention there is provided a DFB laser structure comprising

- a planar, semiconductor material-based active region sandwiched between first and second confinement layers; and

- a grating structure formed in the active region;

wherein grating regions of the grating structure having alternating refractive indices comprise portions of the active region and dielectric material-based regions respectively.

The active region may comprise a multi-quantum well structure.

The active region may comprise an alloy from any two or more of Al, Ga, In, N, P, As or Sb.

The confinement layers may be formed by semiconductor materials.

The active region and first and second confinement layers may be sandwiched between first and second cladding layers.

The first and second cladding layers may be formed by semiconductor materials.

In accordance with a second aspect of the present invention there is provided a method of fabricating a DFB laser structure having a grating structure in a semiconductor material-based active region thereof, the method comprising

forming a dielectric material layer on a confinement layer for the DFB laser structure;

forming the dielectric material layer into a periodic corrugation; and

filling valleys of the periodic corrugation of the dielectric material layer with the semiconductor material;

wherein grating regions of the grating structure having alternating refractive indices comprise portions of the active region and the portions of the dielectric material layer.

The method may comprise patterning and etching the dielectric material layer into the periodic corrugation.

The method may comprise growing multi-quantum well structures of the semiconductor material in the valleys of the periodic corrugation.

The active region may comprise an alloy from any two or more of Al, Ga, In, N, P, As or Sb.

The confinement layer may be formed by semiconductor materials.

In accordance with a third aspect of the present invention there is provided a DBR laser structure comprising

a planar, semiconductor material-based active region sandwiched between first and second confinement layers; and

a grating structure formed on at least one side of the active region and providing reflection and wavelength selection for the DBR laser structure;

wherein grating regions of the grating structure having alternating refractive indices comprise portions of a semiconductor material layer of the DBR structure and dielectric material-based regions respectively.

The active region may comprise a multi-quantum well structure.

The active region may comprise an alloy from any two or more of Al, Ga, In, N, P, As or Sb.

The semiconductor material layer may form part of the first and/or second confinement layers of the DBR laser structure.

The semiconductor material layer may form a cladding layer of the DBR laser structure.

In accordance with a fourth aspect of the present invention there is provided a method of forming a DBR laser structure, the method comprising

forming a planar semiconductor material-based active region sandwiched between first and second confinement layers; and

forming a grating structure on at least one side of the active region and providing reflection and wavelength selection for the DBR laser structure;

wherein grating regions of the grating structure having alternating refractive indices comprise portions of a semiconductor material layer of the DBR structure and dielectric material-based regions respectively.

The active region may comprise a multi-quantum well structure.

The active region may comprise an alloy from any two or more of Al, Ga, In, N, P, As or Sb.

The semiconductor material layer may form part of the first and/or second confinement layers of the DBR laser structure.

The semiconductor material layer may form a cladding layer of the DBR laser structure.

The method may comprise

forming a multi-quantum well layer on the first confinement layer for the DBR laser structure;

forming the grating structure for the DBR laser structure; and

stimulating quantum well intermixing in a portion of the multi-quantum well layer utilising the dielectric material-based regions, to define the active region of the

DBR laser structure comprising another portion of the multi-quantum well layer in which no or less quantum well intermixing occurs.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1 is a cross section view of a DFB laser according to one embodiment of the present invention;

Figure 2 is a graph showing the coupling coefficient for a DFB laser with a grating layer according to the embodiment of Figure 1 and a laser with a normal semiconductor grating;

Figure 3 is a graph showing the reflectivity versus laser cavity length for DFB laser with a grating layer according to the embodiment of Figure 1 and a laser with a normal semiconductor grating;

Figure 4 shows a cross section view of a current flow in a DFB laser, an optical gain distribution, a refractive index distribution and an optical field distribution of a DFB laser according to the embodiment of Figure 1;

Figure 5 shows a cross section view of a current flow in a DFB laser, an optical gain distribution, a refractive index distribution and an optical field distribution of a DFB laser according to another embodiment of the present invention;

Figure 6 is cross section of view of a DFB laser according to yet another embodiment of the invention;

Figures 7a and 7b are plan views of a possible application of conventional DFB lasers and DFB lasers according to embodiments of the present invention;

Figure 8 is a cross-section view of a DBR laser according to yet another embodiment of the present invention;

Figures 9a and 9b are graphs showing the band gap tuning in quantum wells for DBR lasers according to various embodiments of the present invention; and

Figure 10 is a cross-section view of a tuneable DBR laser according to a further embodiment of the present invention.

DETAILED DESCRIPTION

Figure 1 shows a schematic cross-sectional view of a DFB laser according to one embodiment of the present invention.

The DFB laser comprises a substrate 1, a lower cladding layer 2, a lower confinement layer 3, an active region 4, an upper confinement layer 5, an upper cladding layer 6, a contact layer 7 and a grating layer 8. The active region 4 further comprises a plurality of quantum wells 100, each separated by a barrier 101. The grating layer 8 comprises a plurality of grating periods 11. Each grating period 11 further comprises a dielectric material 9 placed adjacent to a semiconductor material 10.

The substrate can be any semiconductor substrate available for epitaxy, for example, GaAs, InP, GaSb, GaN and sapphire. The active region can be realised through the use of bulk materials, quantum wells, quantum wires or quantum dots. The following compounds of SiO_2 , Si_xN_y , AlN , Al_2O_3 , TiO_2 and Ti_2O_5 can be used for the dielectric material 9.

In one embodiment, the DFB laser is constructed from a n-doped InP substrate 1, upon which a $1\text{ }\mu\text{m}$ n-doped InP lower cladding layer 2 is grown in a growth chamber. In another embodiment, the n-doped InP lower cladding layer 2 has a different thickness.

The lower confinement layer 3 is then grown using n-doped lattice matched InGaAsP quaternary material. The lower confinement layer 3 further comprises an outer and an inner layer. The outer layer has an energy band gap wavelength of $1.15\text{ }\mu\text{m}$ and a thickness of 80nm . The inner layer has an energy

band gap wavelength of 1.24 μm and a thickness of 70 nm. In yet another embodiment, the outer and inner layer may have different band gap wavelengths and thickness respectively.

Continuing, the active region 4 is grown above the lower confinement layer 3. In this embodiment, the active region 4 has a multi-quantum well structure further comprising four 7 nm thick 1% compressively strained InGaAsP quantum wells 100, each separated by 10 nm thick InGaAsP barriers 101. The bandgap energy wavelength for the well 100 and the barriers 101 are 1.58 μm and 1.24 μm respectively. In another embodiment, the active region 4 may comprise a different number of quantum wells with different compressive strain.

Above the quantum well active region 4, a p-doped upper confinement layer 5 is grown, the p-doped upper confinement layer 5 having a similar structure and composition to the lower confinement layer 3. The wafer is then moved out of the growth chamber for grating fabrication.

A 50nm thick SiO_2 thin film is deposited onto the wafer by plasma enhanced chemical vapor deposition (PECVD), in the example embodiment. A grating pattern with an appropriate period, generated by either laser holographic method, e-beam lithography or nano-imprinting, is then transferred to the SiO_2 layer by plasma etching or wet chemical etching. P-doped InP upper cladding layer 6 of thickness 1.2 μm is then grown by the technique of selective area growth and epitaxy lateral overgrowth. As a result, the grating layer 8 is formed comprising a periodic corrugation of SiO_2 dielectric material 9 and InP semiconductor material 10. The refractive index of the SiO_2 and InP is 1.46 and 3.19 respectively. The wafer is finally capped with a heavily p-doped InGaAs contact layer 7 with a thickness of 200 nm.

In other embodiments, the SiO_2 thin film may have a different thicknesses. A different material other than SiO_2 may be used. The upper cladding layer 6 may have a different thickness and a material other than p-doped InP used instead. The grating layer 8 may also comprise of materials other than SiO_2 and InP, the other materials having different refractive indices.

The grating layer 8 acts as a wavelength selective mirror. The grating period 11 is chosen so that a significant backward reflection is achieved, giving rise to the feedback necessary for a resonant cavity. The grating period 11 is determined by the following formula:

$$\Lambda = \lambda / 2n$$

where Λ is the period of the grating; λ is the laser wavelength; and n is modal refractive index.

The grating strength affecting the light propagation in the waveguide is described by the coupling coefficient, κ , which is related to the grating shape, the corrugation depth, the distance of the grating layer 8 from the active region and the refractive index difference between the two materials forming the grating layer 8. κ can be described in the following formula:

$$|\kappa| = \frac{\omega \varepsilon_0}{4} \int_{-\infty}^{\infty} \Delta[n^2(x, z)] E^2(x) dx \quad (1)$$

, where E is the optical field distribution

$\Delta[n^2(x, z)]$ is the change in the refractive index of the grating layer

ε_0 is the permittivity of free space and

ω is the light frequency

Figure 2 compares the coupling coefficient versus the grating depth for a conventional grating (represented by the dashed curve, 202) and for a grating representative of the grating layer 8 (represented by the solid curve, 200) of the above embodiment of the invention. The conventional grating is formed by periodic corrugation of InP and InGaAsP with a refractive index of 3.19 and 3.33 respectively. As described earlier, the grating layer 8 is formed by periodic corrugation of SiO₂ and InP with a refractive index of 1.46 and 3.19, respectively. The laser emission wavelength is targeted at 1.55 μm . Both the conventional grating and the grating representative of the grating layer 8 are grown above a confinement layer.

It can be deduced from Figure 2 that the grating layer 8 in the example embodiment will produce a higher coupling coefficient than the conventional

grating for a corresponding grating depth. The grating layer 8 will have a stronger grating effect. By changing the refractive index, through the use of different types of dielectric materials, an optimum refractive index can be found out for different laser structures to get the highest coupling coefficient effect. In addition, the grating layer 8 can be put further away from the active region or can be made thinner to obtain a similar coupling coefficient from the conventional grating of a greater thickness

Figure 3 compares the reflectivity versus laser cavity length for DFB lasers with the conventional grating (curve 300) against DFB lasers with gratings representative of gratings of the example embodiment (curve 302). To obtain 90% reflectivity, the DFB laser with a conventional grating will need a cavity length of about 200 μm . However, the DFB laser with the grating according to the embodiment of the invention only needs a cavity length of about 50 μm . Thus, a four-time reduction in the laser cavity length is achieved. In optical communications, direct modulation speed of the DFB laser is partially constrained by the device RC limitation. A smaller laser length will reduce the RC retardance and thus improve high frequency performance. A smaller device size in photonics integrated circuit applications leads to an increase in the device density and a reduction in the circuit size.

Figure 4 illustrates a current flow distribution 40, an optical gain distribution 42, a refractive index distribution 44, and an optical field distribution 46 along the laser beam guiding direction of the embodiment of the DFB laser shown in Figure 1.

In a DFB laser with a conventional grating structure, the conventional grating is formed using both InP and InGaAsP material that are p-doped and have similar conductivity. The quantum well active region is pumped evenly during current injection. The optical gain distribution and the optical field distribution are uniform along the laser cavity direction.

However, in the embodiment of the DFB laser shown in Figure 4, the optical gain distribution 42 and the optical field distribution 46 are not uniform as current flow 40 inside the active region 4 is not uniform. Current flow 40 to the

region under the dielectric material 9 is substantially blocked by the electrical insulating dielectric material 9. The current 40 will mainly flow through the semiconductor material 10. The current flow 40 into the active region 4 directly below the dielectric portions 9 is lowered. On the contrary, current flow 40 into the active region 4 directly below the semiconductor material 10 is raised. This results in a periodic optical gain distribution 42 in the active region 4. The periodicity of the optical gain distribution 42 is aligned with that of the refractive index distribution 44. Thus, a gain coupling mechanism is introduced into the DFB laser. In addition, the optical field distribution 46 is in phase with the optical gain distribution 42 thus producing an efficient amplification of the optical field distribution 46.

Therefore, a stable single mode oscillation is possible in the example embodiment with no phase shift region and no anti-reflection film at the end facets of the laser cavity, as needed in a pure index coupled DFB laser. A large resistance is also assured for the external back reflection into the laser cavity. Moreover, since the laser is not sensitive to the facet coatings, high output operation is possible by adding anti-reflection and high-reflection coatings to the two facets.

In another embodiment of the present invention, the grating layer 8 can also be put within the active region 4, as shown in Figure 5. This can be realised by either etching the multi-quantum well active region 4 into a periodic corrugation after the active region 4 growth and then filling the grooves with dielectric material 9. Alternatively, the dielectric material 9 can be grown above the lower confinement layer 3, followed by the patterning and etching of the dielectric material 9 into a periodic corrugation. A plurality of quantum wells 100, each separated by a barrier 101 can then be grown.

Since the dielectric material 9 is a good electricity insulator and the grating layer 8 is within the active region 4, the injected current 50 will mainly flow through the quantum wells 100. There is little current leakage to other portions in contrast to the current leakage experienced by conventional gain coupled DFB lasers. There is also little current dispersion through the active region 4. The

optical gain is pinched in the quantum well 100 portions within the grating layer 8. This produces good gain and index coupling and enhances current injection efficiency, thus enhancing the light conversion efficiency of the DFB laser.

Figure 5 also illustrates the current flow distribution 50, optical gain distribution 52, refractive index distribution 54 and optical field distribution 56 along the laser beam guiding direction. Compared to the previous embodiment of the invention illustrated in Figure 4, the refractive index distribution 54 and the optical gain distribution 52 both have higher profiles. Further, as the energy band gap of the dielectric material 9 is very large, an energy potential in the lateral direction will be formed. This enhances carrier confinement in the active region 4 and thus the quantum efficiency.

In another embodiment of the present invention, the grating layer 8 is placed below the active region 4, as shown in Figure 6. The operating mechanism of this embodiment is similar to the embodiments that have been described above.

An application example of an embodiment of the present invention is shown in Figures 7a and 7b. A perspective schematic diagram of monolithically integrated multi-wavelength laser sources constructed by the combination of several separate DFB lasers using conventional gratings is shown in Figure 7a, while Figure 7b shows the laser sources constructed by DFB lasers using grating layers according to embodiments of the present invention. The series of lasers 13, 14, 15 and 16 produce lasers with wavelength λ_1 , λ_2 , λ_3 and λ_4 respectively. In Figure 7a, the series of lasers 13 and 14 are placed along one arm of a Y-coupler 12, while the series of lasers 15 and 16 are placed along the other arm of the Y-coupler 12.

In Figure 7b, the series of lasers 71 and 72 are placed along one arm of the Y-coupler 12, while the series of lasers 73 and 74 are placed along the other arm of the Y-coupler 12. For both Figures 7a and 7b, the outputs of the laser sources 13, 14, 15 and 16, along with the outputs of the laser sources 71, 72, 73 and 74 are combined into a single respective output waveguide through the Y-coupler 12. The periods of the gratings differ so as to provide a certain amount

of spectrum separation between adjacent gratings. The lasers 13, 14, 15, 16, 71, 72, 73 and 74 will be arranged so that the lasing wavelength of each laser is outside the stop bands of all the other lasers 13, 14, 15, 16, 71, 72, 73 and 74. As illustrated in Figure 7b, the DFB lasers using grating layers according to the above embodiments of the invention leads to an integrated device with a shorter length.

Figure 8a shows a schematic cross section of a DBR laser according to another embodiment of the invention. In this embodiment, the grating layer 8 is used as reflectors in a DBR laser. The structure of the DBR laser shown in Figure 8b is similar to the DFB laser depicted in Figure 1. However, in the case of the DBR laser, the grating layer 8 does not lie along the length of the region above the upper cladding layer 6, but substantially occupies the two ends of the laser cavity. These two ends act as reflectors. The reflectors are passive sections and are largely transparent to light with the Bragg wavelength. There are two ohmic contacts 17 and 18, ohmic contact 17 being the anode, while ohmic contact 18 is the cathode, or vice versa. There is no grating layer 8 below the contact 17, where current is injected. Isolation trenches 19 are etched to reach into the upper cladding layer 6 to reduce the current dispersion.

In a conventional DBR laser, the quantum wells in the reflector sections e.g. 80 are etched away after active region growth and then refilled with semiconductor material having higher band gap energy. For example, the InGaAsP quantum wells are etched away from the central laser section and InP is re-grown across the whole wafer. The grating layer is then made by etching certain portions of the re-grown InP layer. The interface where etching and regrowth occurs can cause problems as it introduces extra phases and intensity loss to the propagating light.

In contrast, in an embodiment of the present invention shown in Figure 8b, the active regions e.g. 82 below the grating layers 8 are blurred or eliminated by post growth quantum well intermixing (QWI) technology to form regions 4a. Region 4a now has a band gap shifted to be transparent to the laser wavelength. However, the active regions 4 and the region 4a share substantially the same

waveguide structure. By using QWI technology, no etching and regrowth is needed and therefore no etching and regrowth interface in the light beam guiding direction is introduced.

It has been found that in the example embodiment shown in Figure 8b, the material from the grating layers 8, in particular the dielectric material portions thereof, can facilitate the QWI technology, without the need for additional deposition of dielectric layers. Thus, the example embodiment can provide, as an additional advantage, ease of manufacture for such a DBR laser structure.

Figure 9a illustrates the room temperature photoluminescence (PL) spectra from InGaAsP quantum wells after rapid thermal annealing (RTA) at a temperature of 800°C for a period of 100s. For comparison, curve 90 shows the PL spectrum for the as grown quantum wells. Curves 92, 94 and 96 show the PL spectra under SiN encapsulation, without any encapsulation, and under SiO₂ encapsulation respectively. The PL peak wavelength of the “as grown” curve 90 occurs at 1.562 μm or 0.794 eV in terms of energy, while the PL peak wavelength for the “SiO₂” curve 96 occurs at 1.387 μm or 0.894 eV. The blue shift of the bandgap energy between these two curves is about 100 meV. The PL intensity and the Full Width at Half Maximum of the PL spectrum for the “SiO₂” curve 96 are comparable to the PL intensity and the Full Width at Half Maximum of the PL spectrum for the “as grown” curve 90.

Figure 9b illustrates the room temperature blue shift of the PL peak wavelength for annealing at 750 °C and 800 °C with SiO₂, SiN, and no covering, over a time period from around 30 seconds to around 180 seconds.

It can be seen from Figures 9a and 9b that SiO₂ is effective in enhancing quantum well intermixing. A net blue-shift of nearly 135 nm and 120 nm in PL peak wavelength can be achieved for the DBR laser encapsulated with SiO₂ to those with SiN or no encapsulation after annealing at 800 °C for 100s. This band gap difference for the DBR laser annealed with SiO₂ is large enough for the fabrication of the passive transparent regions e.g. 82 used in the DBR laser of Figure 8b. In the embodiment shown in Figure 8b, the SiO₂ used in constructing the dielectric grating will also be used as the quantum well intermixing enhancing

material. This enables self-alignment of the regions e.g. 82 to the reflecting grating layers 8. No extra dielectric deposition and no extra photolithography alignment processes are needed. In addition, a shorter reflecting grating layer 8 can be created.

In a further embodiment of the present invention, the grating layer 8 is applied in the fabrication of a two-section tuneable DBR laser, as schematically shown in Figure 10. There are two sections in the tuneable DBR laser. The first section is the laser section with an electrical contact 17a and an injection current I_1 . The second section is the tuning section with an electrical contact 17b and an injection current I_2 . The tuning section comprises a grating layer 8 which acts as a wavelength selective reflector. The refractive index of the tuning section can be changed either by quantum confined Stark effect or by changing the injection current I_2 . This will in turn change the modal refractive index of the grating layer 8 and thus change the emitted laser wavelength. The tuning section should have a band gap energy larger than the laser section. Similarly, the one-step self-aligned quantum well intermixing technology, described in the embodiment illustrated by Figure 8b in which SiO_2 is used as the intermixing enhancing material, can be used to blue shift the band gap energy of the tuning section.

The embodiments of the present invention can be applied in the fabrication of DFB or DBR lasers based on (In)GaN materials. Most of the short wavelength lasers using GaN alloys are grown on sapphire substrate, which is very tough and difficult to cleave. It is also not an easy task to obtain a cleaved facet to form the resonant cavity in a GaN substrate. As such, the use of the gratings described in the above embodiments provides not only the reflector needed for lasing to occur, but also to produce a laser with a purer spectrum.

In embodiments of present invention, a dielectric grating formed by periodically corrugation of dielectric material and semiconductor material is used to replace the traditional grating formed by periodically corrugation of two different semiconductor materials. The dielectric material can be, for example, any of SiO_2 , Si_xN_y , AlN , Al_2O_3 , TiO_2 , Ti_2O_5 , etc., while the semiconductor material can be an alloy from any combinations of atoms from group III or group V. Due to

the large refractive index difference between the dielectric material and the semiconductor material, the dielectric grating can provide a much higher coupling coefficient and thus make the device structure design more flexible. For example, a much shorter grating length can give the same reflectivity needed to form the laser resonant cavity.

In embodiments of the invention, the dielectric grating replaces the conventional grating below or upon the active region in a DFB laser. Due to the current blocking properties of the dielectric material, gain coupling mechanism is introduced so as to enhance the device single mode yield and ease the fabrication process.

In embodiments of the invention, the dielectric grating is within the active region of a DFB laser. There is no gain in the dielectric material portion in a grating and no current flow through it. Both the gain coupling and the index coupling are maximized. The laser enjoys high quantum efficiency as well as the advantages bring by the complex coupling mechanism.

In embodiments of the invention, the SiO_2 gratings are used to replace the conventional gratings in the reflector sections in a DBR laser. The bandgap of the reflector sections are tuned to be transparent to the laser wavelength by one-step quantum well intermixing technology using the SiO_2 gratings themselves as the intermixing enhancement masks. This will save the etch-regrowth process to fabricate the distributed reflector in a DBR laser.

In embodiments of the invention, the SiO_2 grating is used in the reflector section in a two-section tuneable laser. The bandgap of the reflector section is tuned to be transparent to the laser wavelength by one-step quantum well intermixing technology using the SiO_2 grating itself as the intermixing enhancement mask. The changing of the refractive index in the reflector sections will change the peak position of the Bragg wavelength and thus change the laser output wavelength. The refractive index in the reflector section can be changed by means of either current injection or the application of electric field.

Embodiments of the present invention may be beneficial for the InGaN/GaN material system, because of the difficulties in getting a cleaved facet.

The strong coupling effect in the embodiments may be used to replace the two mirrors required for a resonant cavity.

The grating in embodiments of the present invention may be made in the form of chirped grating, sampling grating, etc., and can be applied to semiconductor lasers consisting of any III-V materials in the active region.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

CLAIMS

1. A DFB laser structure comprising
a planar, semiconductor material-based active region sandwiched between first and second confinement layers; and
a grating structure formed in the active region;
wherein grating regions of the grating structure having alternating refractive indices comprise portions of the active region and dielectric material-based regions respectively.
2. The DFB laser structure as claimed in claim 1, wherein the active region comprises a multi-quantum well structure.
3. The DFB laser structure as claimed in claims 1 or 2, wherein the active region comprises an alloy from any two or more of Al, Ga, In, N, P, As or Sb.
4. The DFB laser structure as claimed in any one of the preceding claims, wherein the confinement layers are formed by semiconductor materials.
5. The DFB laser structure as claimed in any one of the preceding claims, in which the active region and first and second confinement layers are sandwiched between first and second cladding layers.
6. The DFB laser structure as claimed in claim 5, wherein the first and second cladding layers are formed by semiconductor materials.
7. A method of fabricating a DFB laser structure having a grating structure in a semiconductor material-based active region thereof, the method comprising
forming a dielectric material layer on a confinement layer for the DFB laser structure;
forming the dielectric material layer into a periodic corrugation; and
filling valleys of the periodic corrugation of the dielectric material layer with the semiconductor material;
wherein grating regions of the grating structure having alternating refractive indices comprise portions of the active region and the portions of the dielectric material layer.
8. The method as claimed in claim 7, comprising patterning and etching the dielectric material layer into the periodic corrugation.

9. The method as claimed in claims 7 or 8, comprising growing multi-quantum well structures of the semiconductor material in the valleys of the periodic corrugation.

10. The method as claimed in any one of claims 7 to 9, wherein the active region comprises an alloy from any two or more of Al, Ga, In, N, P, As or Sb.

11. The method as claimed in any one of claims 7 to 9, wherein the confinement layer is formed by semiconductor materials.

12. A DBR laser structure comprising
a planar, semiconductor material-based active region sandwiched between first and second confinement layers; and

a grating structure formed on at least one side of the active region and providing reflection and wavelength selection for the DBR laser structure;

wherein grating regions of the grating structure having alternating refractive indices comprise portions of a semiconductor material layer of the DBR structure and dielectric material-based regions respectively.

13. The DBR laser structure as claimed in claim 12, wherein the active region comprises a multi-quantum well structure.

14. The DBR laser structure as claimed in claims 12 or 13, wherein the active region comprises an alloy from any two or more of Al, Ga, In, N, P, As or Sb.

15. The DBR laser structure as claimed in any one of claims 12 to 14, wherein the semiconductor material layer forms part of the first and/or second confinement layers of the DBR laser structure.

16. The DBR laser structure as claimed in any one of claims 12 to 14, wherein the semiconductor material layer forms a cladding layer of the DBR laser structure.

17. A method of forming a DBR laser structure, the method comprising
forming a planar semiconductor material-based active region sandwiched between first and second confinement layers; and

forming a grating structure on at least one side of the active region and providing reflection and wavelength selection for the DBR laser structure;

wherein grating regions of the grating structure having alternating refractive indices comprise portions of a semiconductor material layer of the DBR structure and dielectric material-based regions respectively.

18. The method as claimed in claim 17, wherein the active region comprises a multi-quantum well structure.

19. The method as claimed in claims 17 or 18, wherein the active region comprises an alloy from any two or more of Al, Ga, In, N, P, As or Sb.

20. The method as claimed in any one of claims 17 to 19, wherein the semiconductor material layer forms part of the first and/or second confinement layers of the DBR laser structure.

21. The method as claimed in any one of claims 17 to 19, wherein the semiconductor material layer forms a cladding layer of the DBR laser structure.

22. The method as claimed in any one of claims 17 to 21, comprising forming a multi-quantum well layer on the first confinement layer for the DBR laser structure;

forming the grating structure for the DBR laser structure; and

stimulating quantum well intermixing in a portion of the multi-quantum well layer utilising the dielectric material-based regions, to define the active region of the DBR laser structure comprising another portion of the multi-quantum well layer in which no or less quantum well intermixing occurs.