

Description

The present invention relates to distributed feedback (DFB) lasers and in particular but not exclusively to DFB semiconductor injection lasers.

5 With reference to earlier application no. GB-A-2209408, the Applicant has voluntarily limited the scope of the present application, and submitted separate claims for the United Kingdom.

DFB lasers do not utilise the cavity mirrors of conventional Fabry-Perot systems, but rather rely on backward Bragg scattering from periodic perturbations of the refractive index and/or gain of the laser medium to provide the optical feedback necessary for laser operation. DFB structures have the advantage of providing
10 better frequency stability of the mode of oscillation than Fabry-Perot structures.

In semiconductor DFB lasers, the periodic perturbations are generally provided by means of a grating formed, usually, in a semiconductor layer adjacent the device's active layer, the teeth and grooves of the grating extending orthogonally to the device's optical axis. Typically the grating extends throughout the entire length of the laser, but in some devices the grating is shorter than the device, the grating ends being remote from
15 the device ends.

The wavelength sensitivity of the Bragg effect results in DFB lasers exhibiting a high degree of spectral selection. The narrow linewidth of DFB lasers means that they are very attractive for use in optical communications systems, not least because of the effective increase in bandwidth that can be achieved as a result of the reduced dispersion consequent on the use of a narrower linewidth source. Unfortunately, however, the optical output of DFB lasers, while of narrow linewidth, is not absolutely monochromatic: generally two and sometimes three longitudinal modes will be supported simultaneously, the dominant mode having the highest intensity output. If the power difference between the dominant and subordinate modes is great enough, the laser's output can be considered for some purposes to be single mode. The problem lies in ensuring a sufficiently great power difference. Typically, the aim is to achieve side to main mode power ratios of - 40dB or better under
20 the most severe operating conditions - in particular, under direct modulation.

As reported by Haus and Shank in IEEE Journal of Quantum Electronics, Vol. QE12, No. 9, pp 532-539, 1976, the mode spectrum of the original DFB laser as analyzed by Kogelnik and Shank (J. Appl. Phys., Vol. 43, pp2327-2335, 1972) consisted of modes of equal threshold on either side of a gap at a 'centre' frequency. Haus and Shank note that this threshold degeneracy is a disadvantage in practical applications where single-mode operation at a predictable frequency is desired, and they show that antisymmetric tapering of the coupling coefficient of the period of the structure may be utilized to remove the threshold degeneracy. Haus and Shank established that all structures with an antisymmetric taper of K (the feedback parameter of Kogelnik and Shank) support a mode at the centre frequency of the local stopbands. This mode has a particularly low threshold when used in a laser cavity.
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Haus and Shank found that DFB lasers with a stepped-K structure, that is one with a phase shift between a first section of grating and a second section of grating, had no threshold degeneracy and had much better threshold discrimination between the fundamental mode and the first higher order mode. They also found the frequency separation between the dominant mode and the first order mode to be much greater for the stepped structure than for the uniform structure.
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As a result of the work by Haus and Shank, DFB lasers are now made with phase-shifted gratings.

Ideally, the lengths of the first and second sections are each equal to half the total grating length. While the use of phase-shifted gratings is distinctly beneficial, there is still a demand for DFB lasers with improved threshold discrimination between the fundamental mode and the first higher order mode.

According to a first aspect of the present invention there is provided a distributed feedback semiconductor laser wherein the means which provide the feedback necessary for laser operation are distributed throughout a major portion of the length of the laser, the level of feedback provided by said means varies throughout said major portion, is a maximum at or near the middle of said means and tends towards zero adjacent at least one of the ends of said major portion.
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We have discovered that if, instead of the feedback being constant throughout the length of the means for providing the distributed feedback, it is modified by a function such that it is a maximum at or near the middle of said means and tends towards zero at one or both of the ends of the means, improved mode discrimination can be achieved.
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Preferably the function is such that there are no abrupt changes in feedback amplitude throughout the length of the means.

Preferably the means comprises a grating. Preferably the DFB laser is phase-adjusted. Preferably the phase adjustment is provided by means of a phase-shift in the means. Preferably the phase-shift occurs at or near the mid point along the length of the means.
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According to a second aspect of the present invention there is provided a distributed feedback laser where-

in a grating is provided to give optical feedback, the optical coupling of the grating varying with position along its length, characterised in that throughout the length of the grating there are no abrupt changes in the degree of coupling, the degree of coupling is at a maximum at or near the middle of the grating, and in that adjacent at least one of the ends of the grating the coupling tends smoothly to zero.

Following the work of Haus and Shank described above, others have considered how, other than by building a phase shift into the grating, phase-adjustment could be implemented in semiconductor DFB lasers. Sekartedjo, Broberg, Koyama, Furuya and Suematsu in Jap.J.Appl.Phys., Vol. 23, No. 10, 1984, pp791-794, describe a phase-adjusted distributed reflector laser in which phase adjustment is accomplished by providing a trench 0.15 μ m deep and 12 μ m long across the width of the laser's grooved substrate (the device being approximately 800 μ m long). Using liquid phase epitaxy (LPE) a buffer layer nominally 0.15 μ m thick was grown over the grating, filling the trench (the LPE growth rate being higher in the trench). The device's active layer was then grown on the buffer layer using LPE, the remaining processing steps being conventional. The optical propagation constant over the trench is different to that in the rest of the waveguide, thereby producing a phase shift in the propagating wave.

Soda, Wakao, Sudo, Tanahashi and Imai have proposed, Electronics Lett. Vol. 20, No. 24, pp1016-1018, a phase-adjusted DFB laser in which phase-adjustment is achieved as the result of differences in propagation constant between a 60 μ m long phase-adjustment region which is wider or narrower than the bulk 'uniform' regions at either end of the laser. The difference in width between the propagation region and the 'uniform' regions is achieved by varying the stripe width. The corrugations of the grating are formed throughout the length of the device (400 μ m) without a phase shift.

In none of the papers referenced above is there any suggestion that modifying the coupling of the grating in such a way that it tends to zero is in any way advantageous.

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

- Figures 1 to 5 are a series of sections in the same plane showing the stages in the production of a DFB laser of known type;
- Figure 6 is a partially exploded perspective view of a conventional ridge waveguide DFB semiconductor laser;
- Figure 7 is a similar perspective view of a DFB ridge waveguide laser according to the present invention, illustrating the new grating arrangement;
- Figure 8a is a schematic plan view of the grating of the laser shown in Figure 7;
- Figure 8b is a plot of tooth density against position for the grating of Figure 8a;
- Figure 9 is a similar schematic perspective view of a phase-shifted laser according to the present invention;
- Figure 10 is a schematic view of a grating for use in a laser according to the invention, the grating providing non-uniform coupling as the result of variations in tooth depth;
- Figures 11a and 11b are top and side schematic views of an alternative grating for use in a laser according to the invention, the grating providing non-uniform coupling as a result of variations in tooth density;
- Figure 12 is a plot of effective e-beam exposure dose received by DFB grating lines when a parabolic weighting function is used without correction for proximity effects;
- Figure 13 is a similar plot showing the effect of correcting for proximity effects;
- Figure 14 shows gain difference measured as a function of KL for conventional PSDFB lasers and those according to the present invention; and
- Figure 15 shows yields of devices satisfying a given $\Delta\alpha \cdot L$ requirement for conventional PSDFB and those according to the present invention.

In the following description, and elsewhere in this specification, terms such as "on top of" and "underside" are used. These terms are used for convenience only and should not be taken to denote a particular orientation of any device unless it is clear from the context that a particular orientation is intended.

In Figure 6 an example of a semiconductor DFB laser of conventional type, specifically a DFB ridge-waveguide laser as described in our European patent application 85301599, 8, is shown, and it is in relation to this type of laser that the invention will be particularly described. It should be understood, however, that the present invention is equally applicable to other laser structures, including glass lasers and dye lasers, and particularly to other semiconductor laser structures, for example buried-heterostructure lasers and multiple quantum well lasers.

The first stages in the production of the device, as far as the section shown in Figure 1, are as follows. Onto the (100) face (2 in Figure 1) of a heavily S-doped InP (n^+ -type) substrate 1 approximately 200 μ m thick were grown by liquid phase epitaxy (LPE) a series of three layers of quaternary materials 3, 4, and 5 each

0.2 μm thick. Layer 3 is Te-doped (n-type) of nominal composition $\text{Ga}_{0.17}\text{In}_{0.83}\text{As}_{0.36}\text{P}_{0.64}$ of band gap equivalent 1.15 μm as determined by photoluminescence. Layer 4 is undoped material of nominal composition $\text{Ga}_{0.39}\text{In}_{0.61}\text{As}_{0.88}\text{P}_{0.12}$ of nominal band gap equivalent 1.52 μm . Layer 5 is similar to layer 3 except that it is Zn-doped (p-type). Layer 4, it will be appreciated, is the active layer in the finished device and layers 3 and 5 are the lower and upper confinement (or "buffer") layers.

Next, layer 5 was corrugated by chemical etching through an electron-beam-exposed resist mask in the manner described by Westbrook et al, Electronics Letters, 1982, volume 18, pages 863-865. The distributed feedback corrugations are second-order of nominal period 0.46 μm , running in the 110 direction, the etching being self-limiting and resulting in triangular grooves with (111)A side walls. The grooves are approximately 0.16 μm deep. The self-limiting nature of the etching process makes for reproducibility and control of the laser feedback strength.

Then corrugated layer 5 was overgrown with a layer 7 Zn-doped (p-type) indium phosphide by atmospheric pressure metal organic chemical vapour deposition (MOCVD) while maintaining the integrity of the gratings as previously described (European patent application 84300240.3 and also Nelson et al, Electronics Letters, 1983, volume 19, pages 34 to 36). To achieve this, trimethylindium, triethylphosphine, dimethylzinc, phosphine, and hydrogen were passed over the sample at 100°C and the sample was heated rapidly to 650°C whereupon growth occurred. Layer 7 was approximately 1.5 μm thick.

Then, also by MOCVD, a layer 8 approximately 0.1 μm thick of heavily Zn-doped (p⁺-type) ternary material was grown. The material had the nominal composition $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$.

To complete the structure of Figure 1, a layer 9 of silica, 0.2 μm thick, was grown on top of layer 8 by chemical vapour deposition from silane and oxygen.

Then the substrate was thinned to 100 μm by chemical etching, and the back contact of the laser (i.e. the contact on the underside of thinned layer 1) was made by evaporation of tin and gold and subsequent alloying.

The immediately subsequent treatment of the upper layers, as far as Figure 2, was as follows. 0.1 μm of titanium (layer 10) and 0.1 μm of gold (layer 11) were evaporated onto the silica layer 9. Then about 1 μm of a positive resist Kodak 820 was applied to the gold and a dark field mask at right angles to the grating was used to make a stripe window 13 between areas of resist 12 and 12'. Windows of 2 μm , 4 μm , 6 μm , and 15 μm were made on a single wafer.

The steps as far as Figure 3 were as follows. The structure was exposed to an solution of potassium iodide (4 g) and iodine (1 g) in 40 ml of water at 20°C for 1 to 1½ minutes (which etchant attacks gold layer 11) and to "Countdown silicon dioxide etch (10:1)" for 2 to 2½ minutes at 20°C (which etchant attacks titanium layer 10 and silica layer 9). The result was an undercut etching down to the top layer 8 of semiconductor material. By exposing this sequentially to filaments of evaporating titanium and gold, an image 14, 15 of the window was obtained on the exposed semiconductor. At the same time, titanium layers 16, 16' and gold layers 17, 17' were deposited on top of the resist 12, 12'. The wire filaments used were 10 cm away from the target and the thickness of each metal deposited was about 0.1 μm .

Then the structure shown in Figure 3 was soaked in acetone for two minutes so as to remove the resist 12, 12' and therewith layers 16, 16', 17, and 17'. The result as shown in Figure 4 is an "initial semiconductor structure" as referred to with respect to the second aspect of the invention carrying two sequential layers of metal comprising sub-layers 14 and 15 and separate layers of dielectric 9 and 9', which latter are themselves in this case overlaid with metal 10 and 11 and 10' and 11'. The distance between the edges of the metal layers 14, 15 and the edge of the dielectric 9, 9' was approximately 4 μm .

By treating this structure with 16 weight per cent aqueous HNO_3 at 20°C for 20 seconds to 1 minute (to attack ternary layer 8) and then with a 1:1 mixture by volume of concentrated hydrochloric acid and 90 per cent orthophosphoric acid at 20°C for 30 to 40 seconds (to attacking quaternary layer 5), the result shown in Figure 5 is received.

In Figure 5, the etching through layers 8 and 7 has been shown as vertical, although in practice this is unlikely to be the case. It will be seen that, in the terminology previously used, the base semiconductor portion is constituted by layers 1, 3, 4, and 5; the first elevated semiconductor portion (constituting the ridge of the laser) by 7" and 8"; the second elevated semiconductor portions by 7 and 8; and the third by 7' and 8'. It will be noted that while the first such portion carries metal layers titanium 14 and gold 15 in electrical contact therewith the other portions carry the dielectric silica 9 and 9'. The insides of channels 16, 17 are substantially free of dielectric and metal.

As is conventional, all the steps above were in fact performed on a wafer which we then cut up to yield several devices, a single such device being shown schematically in Figure 6. In Figure 6, the second and third elevated semiconductor portions are omitted so as to show clearly the relative orientation of the ridge and the grating. The reference numerals up to 15 have the same significance as previously. Facet 18 of the device is a cleaved facet, the other three side facets such as 19 being treated (scribed or AR coated) so as to suppress

Fabry-Perot laser modes other than the mode selected by the DFB grating.

Figure 7 shows schematically one embodiment of the present invention. As is clear from a comparison of Figures 6 and 7, in this embodiment of the invention, the tooth density of the grating varies along the grating's length. By reference to Figures 8a and 8b, it can be seen that the tooth density varies parabolically, with tooth spacing increasing towards each end of the grating. It should be noted that the tooth spacing is not in fact a continuous variable; the spacing between adjacent teeth centres is an integer times the fundamental Bragg period.

In Figure 9, a buried heterostructure laser according to the invention is shown with a grating similar to that shown in Figure 8 apart from the incorporation of a phase shift at its mid-point.

The end facets of the devices shown in Figures 8 and 9 are antireflection coated. In general it is preferable to have as low a reflectivity as possible, because the benefit of devices according to the invention is increased as facet reflectivity is reduced, at least down to 0.1 percent. Preferably, therefore, facet reflectivities of 1 percent or less are used. More preferably, the facet reflectivities are less than or equal to 0.5 percent. Still more preferably, the facet reflectivities are 0.1 percent or less. All reflectivities in this specification are determined at an operating wavelength of the device, as is conventional.

As an alternative to varying tooth spacing, grating coupling may be varied according to the invention by varying tooth depth. A schematic example of this approach is shown in Figure 10. If electron-beam lithography is used in the grating definition process, a grating in which tooth depth varies, as shown in Figure 10, may be produced by varying the e-beam exposure dose. Schematic sectional views of the alternative structure, in which coupling is varied by varying tooth separation also shown in Figure 8, is shown in Figures 11a and 11b.

Using electron-beam lithography, this form of grating is produced with a uniform e-beam dose with an appropriate exposure pattern (in effect, grooves/teeth are left out with increasing frequency as the grating ends are approached). The proximity effects which are experienced in electron-beam lithography mean that using the same e-beam dose in writing each line results in lower exposure for lines which are widely spaced than for those which are more closely spaced. Figure 12 illustrates the effective exposure dose received by DFB grating lines when a parabolic weighting function is used and no correction is made for proximity effects. The lowest exposure is received by lines towards the end of the grating which receive only 73 per cent of the peak exposure dose. Such an approach results in faint, uneven or missing grating lines. This problem can be overcome by using as near as possible a uniform e-beam dose in writing the grating. Figure 13 illustrates the effective exposure dose received by a DFB grating (with the same parabolic weighting function as that used for Figure 12) when proximity effect correction is used. By increasing the writing time for lines at the end of the grating the worst case (minimum) exposure has been increased to 94.4 per cent of the peak exposure dose, resulting in a much more uniform etching of grating lines. Since this approach is very easy to implement it is the preferred approach.

It is of course possible to vary grating coupling by combining tooth depth and density variations.

Grating coupling may be varied in a yet further way, by directly varying the refractive index of the layer (waveguide) in which the grating is formed. The refractive index may for example be varied by means of a local implant of diffusion of some index-controlling material. With such an approach, a conventional grating structure could be used.

The present invention is based on our appreciation that if the level of feedback is gradually reduced to zero at the ends of a laser grating, the side modes are suppressed, increasing the theoretical gain difference, MSR and single mode device yield (that is the percentage of devices from a given wafer which are in fact useably single moded). Our calculations have also shown that by combining this weighting with a central phase shift, a much larger mode suppression ratio can be achieved than is possible using the phase shift alone. Figure 14 shows the gain difference $\Delta\alpha \cdot L$ between the principal lasing mode and the strongest side-mode calculated as a function of KL for phase shifted structures of this type, together with similar calculations for a conventional phase shifted DFB laser, assuming zero facet reflectivity. As can be seen from this figure, $\Delta\alpha \cdot L$ for these non-uniform gratings is more than twice that for the simple phase-shifted DFB (PSDFB) at $KL=2$, and continues to rise at larger KL . This increase in $\Delta\alpha \cdot L$ leads to a substantially larger single-mode suppression ratio. Figure 15 shows the percentage yield of devices satisfying a given $\Delta\alpha \cdot L$ requirement, again calculated for weighted and uniform PSDFB structures, assuming a residual facet reflectivity of 0.3 per cent (a typical facet reflectivity for AR coated facets of modest quality) and a random distribution of facet phases. As those skilled in the art will appreciate, a low but non-zero residual facet reflectivity will tend to improve the single-modedness of uniform PSDFB devices, but will tend to reduce the benefits of the present invention relative to the performance of equivalent devices having zero facet reflectivities. Despite this, it is clear from this graph that non-uniform gratings of this type (according to the present invention) produce much higher yields of devices with large $\Delta\alpha \cdot L$ than are achievable with uniform PSDFB structures.

So far the invention has been described with reference to symmetrical grating structures, in which coupling

is reduced equally towards each end of the grating. There are, however, applications where it would be advantageous if the grating had an asymmetrical structure. In particular there would be advantages in having grating coupling tending to zero at only one end of the grating.

As has already been mentioned, the present invention may be realised in some form other than a semiconductor laser, such as, for example, a dye laser or a doped-glass laser.

For the avoidance of doubt, it should be noted that the terms distributed feedback laser and DFB laser used in this specification are not to be taken as referring to distributed bragg reflector (DBR) lasers.

In DBR lasers the grating region is spaced, in the direction of propagation (z), from the active region. In effect the grating or gratings function as wavelength-selective mirrors spaced, in the direction of propagation, from the active region. Conversely, in DFB laser the grating, while generally spaced in the X or Y direction from the active layer, lies parallel to the active layer throughout the entire grating length (but not necessarily throughout the entire active layer length).

Claims

Claims for the following Contracting States : AT, BE, CH, DE, DK, ES, FR, GR, IT, LI, LU, NL, SE

1. A distributed feedback laser wherein the means (6) which provide the feedback necessary for laser operation are distributed throughout a major portion of the length of the laser, the level of feedback provided by said means (6) varies throughout said major portion, is a maximum at or near the middle of said means and tends towards zero adjacent at least one of the ends of said major portion.
2. A laser as claimed in claim 1 wherein, in use, substantially all the optical feedback within the device is provided by said means (6).
3. A laser as claimed in claim 1 or claim 2, wherein the amount of feedback provided throughout said major portion varies without abrupt changes.
4. A laser as claimed in any one of the preceding claims wherein the means (6) comprises a grating.
5. A laser as claimed in claim 4, wherein the variation in the level of feedback provided by said means (6) is the result of a property of the grating varying along the length of the grating.
6. A laser as claimed in claim 5, wherein the grating property which varies is tooth depth.
7. A laser as claimed in claim 5, wherein the grating property which varies is tooth spacing.
8. A laser as claimed in claim 5, in which the tooth depth and tooth pitch of the grating are both varied.
9. A laser as claimed in any one of claims 4 to 8 wherein the grating extends along substantially the entire length of the laser.
10. A laser as claimed in any one of the preceding claims, wherein the laser comprises a semiconductor injection laser.
11. A laser as claimed in claim 10, having at least one optical facet (18, 19) which is antireflection coated and which has a reflectivity at an operating wavelength of the device which is 1 percent or less.
12. A laser as claimed in claim 9 or claim 10 as dependent on claim 3, wherein the grating is formed in one surface of a waveguiding layer (5), the laser additionally comprising an active layer (4), variations in the thickness and/or width of the waveguiding layer (5) resulting in said feedback variation.
13. A laser as claimed in any one of claims 9, 10 or 11, wherein the laser comprises a ridge-waveguide structure.
14. A laser as claimed in any one of claims 9 to 12, wherein the laser comprises a buried-heterostructure.



is reduced equally towards each end of the grating. There are, however, applications where it would be advantageous if the grating had an asymmetrical structure. In particular there would be advantages in having grating coupling tending to zero at only one end of the grating.

As has already been mentioned, the present invention may be realised in some form other than a semiconductor laser, such as, for example, a dye laser or a doped-glass laser.

For the avoidance of doubt, it should be noted that the terms distributed feedback laser and DFB laser used in this specification are not to be taken as referring to distributed bragg reflector (DBR) lasers.

In DBR lasers the grating region is spaced, in the direction of propagation (z), from the active region. In effect the grating or gratings function as wavelength-selective mirrors spaced, in the direction of propagation, from the active region. Conversely, in DFB laser the grating, while generally spaced in the X or Y direction from the active layer, lies parallel to the active layer throughout the entire grating length (but not necessarily throughout the entire active layer length).

Claims

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1. A distributed feedback laser wherein the means (6) which provide the feedback necessary for laser operation are distributed throughout a major portion of the length of the laser, the level of feedback provided by said means (6) varies throughout said major portion, is a maximum at or near the middle of said means and tends towards zero adjacent at least one of the ends of said major portion.
2. A laser as claimed in claim 1 wherein, in use, substantially all the optical feedback within the device is provided by said means (6).
3. A laser as claimed in claim 1 or claim 2, wherein the amount of feedback provided throughout said major portion varies without abrupt changes.
4. A laser as claimed in any one of the preceding claims wherein the means (6) comprises a grating.
5. A laser as claimed in claim 4, wherein the variation in the level of feedback provided by said means (6) is the result of a property of the grating varying along the length of the grating.
6. A laser as claimed in claim 5, wherein the grating property which varies is tooth depth.
7. A laser as claimed in claim 5, wherein the grating property which varies is tooth spacing.
8. A laser as claimed in claim 5, in which the tooth depth and tooth pitch of the grating are both varied.
9. A laser as claimed in any one of claims 4 to 8 wherein the grating extends along substantially the entire length of the laser.
10. A laser as claimed in any one of the preceding claims, wherein the laser comprises a semiconductor injection laser.
11. A laser as claimed in claim 10, having at least one optical facet (18, 19) which is antireflection coated and which has a reflectivity at an operating wavelength of the device which is 1 percent or less.
12. A laser as claimed in claim 9 or claim 10 as dependent on claim 3, wherein the grating is formed in one surface of a waveguiding layer (5), the laser additionally comprising an active layer (4), variations in the thickness and/or width of the waveguiding layer (5) resulting in said feedback variation.
13. A laser as claimed in any one of claims 9, 10 or 11, wherein the laser comprises a ridge-waveguide structure.
14. A laser as claimed in any one of claims 9 to 12, wherein the laser comprises a buried-heterostructure.



15. A laser as claimed in any one of claims 9 to 13, comprising an indium phosphide substrate.
16. A laser as claimed in any one of the preceding claims, the laser having an operating wavelength of between 1.3 and 1.55 μ m.
17. A distributed feedback laser wherein a grating (6) is provided to give optical feedback, the optical coupling of the grating varies with position along its length, there are no abrupt changes in the degree of coupling throughout the length of the grating, the degree of coupling is at a maximum at or near the middle of the grating (6), and the coupling tends smoothly to zero adjacent at least one of the ends of the grating.

Claims for the following Contracting State : GB

1. A distributed feedback semiconductor laser comprising an indium phosphide substrate wherein the means (6) which provide the feedback necessary for laser operation are distributed throughout a major portion of the length of the laser, the level of feedback provided by said means (6) varies throughout said major portion, is a maximum at or near the middle of said means and tends towards zero adjacent at least one of the ends of said major portion.
2. A laser as claimed in claim 1 wherein, in use, substantially all the optical feedback within the device is provided by said means (6).
3. A laser as claimed in claim 1 or claim 2, wherein the amount of feedback provided throughout said major portion varies without abrupt changes.
4. A laser as claimed in any one of the preceding claims wherein the means (6) comprises a grating.
5. A laser as claimed in claim 4, wherein the variation in the level of feedback provided by said means (6) is the result of a property of the grating varying along the length of the grating.
6. A laser as claimed in claim 5, wherein the grating property which varies is tooth depth.
7. A laser as claimed in claim 5, wherein the grating property which varies is tooth spacing.
8. A laser as claimed in claim 5, in which the tooth depth and tooth pitch of the grating are both varied.
9. A laser as claimed in any one of claims 4 to 8 wherein the grating extends along substantially the entire length of the laser.
10. A laser as claimed in any one of the preceding claims, having at least one optical facet (18, 19) which is antireflection coated and which has a reflectivity at an operating wavelength of the device which is 1 percent or less.
11. A laser as claimed in any one of the preceding claims, wherein the grating is formed in one surface of a waveguiding layer (5), the laser additionally comprising an active layer (4), variations in the thickness and/or width of the waveguiding layer (5) resulting in said feedback variation.
12. A laser as claimed in any one of the preceding claims, wherein the laser comprises a ridge-waveguide structure.
13. A laser as claimed in any one of the preceding claims, wherein the laser comprises a buried-heterostructure.
14. A laser as claimed in any one of the preceding claims, the laser having an operating wavelength of between 1.3 and 1.55 μ m.
15. A distributed feedback laser wherein a grating (6) is provided to give optical feedback, the optical coupling of the grating varies with position along its length, there are no abrupt changes in the degree of coupling throughout the length of the grating, the degree of coupling is at a maximum at or near the middle of the



grating (6), and the coupling tends smoothly to zero adjacent to at least one of the ends of the grating.

Patentansprüche

Patentansprüche für folgende Vertragsstaaten : AT, BE, CH, DE, DK, ES, FR, GR, IT, LI, LU, NL, SE

1. Laser mit verteilter Rückkopplung, bei dem die Mittel (6), welche die für den Laserbetrieb notwendige Rückkopplung vorsehen, über einen Hauptabschnitt der Länge des Lasers verteilt sind, wobei sich das durch die Mittel (6) vorgesehene Rückkopplungsniveau über den Hauptabschnitt ändert, ein Maximum bei oder nahe der Mitte der Mittel aufweist und nahe zumindest einem der Enden des Hauptabschnitts in Richtung Null geht.
2. Laser nach Anspruch 1, in dem in Verwendung im wesentlichen die gesamte optische Rückkopplung in der Vorrichtung durch die Mittel (6) vorgesehen ist.
3. Laser nach Anspruch 1 oder 2, in dem sich der über den Hauptabschnitt vorgesehene Rückkopplungsbetrag ohne abrupte Änderungen ändert.
4. Laser nach einem beliebigen der vorangehenden Ansprüche, in dem die Mittel (6) ein Raster enthalten.
5. Laser nach Anspruch 4, in dem die Veränderung des durch die Mittel (6) vorgesehenen Rückkopplungsniveaus das Ergebnis einer Eigenschaft des Rasters ist, die sich entlang der Länge des Rasters ändert.
6. Laser nach Anspruch 5, in dem die sich ändernde Rastereigenschaft die Zahntiefe ist.
7. Laser nach Anspruch 5, in dem die sich ändernde Rastereigenschaft der Zahnabstand ist.
8. Laser nach Anspruch 5, in dem die Zahntiefe und der Zahnabstand des Rasters geändert werden.
9. Laser nach irgendeinem der Ansprüche 4 bis 8, in dem sich das Raster entlang im wesentlichen der gesamten Länge des Lasers erstreckt.
10. Laser nach irgendeinem der vorangehenden Ansprüche, in dem der Laser einen Halbleiterinjektionslaser enthält.
11. Laser nach Anspruch 10, mit einer optischen Facette (18, 19), welche antireflexionsbeschichtet ist und eine Reflektivität von 1 % oder weniger bei einer Betriebswellenlänge des Geräts aufweist.
12. Laser nach Anspruch 9 oder dem von Anspruch 3 abhängigen Anspruch 10, in dem das Raster durch eine Oberfläche einer Wellenführungsschicht (5) gebildet ist, wobei der Laser zusätzlich eine Aktivschicht (4) aufweist und Veränderungen der Dicke und/oder Breite der Wellenführungsschicht (5) zu der Rückkopplungsveränderung führen.
13. Laser nach irgendeinem der Ansprüche 9, 10 oder 11, in dem der Laser einen Steghohlleiteraufbau aufweist.
14. Laser nach irgendeinem der Ansprüche 9 bis 12, in dem der Laser eine beerdigte Heterostruktur aufweist.
15. Laser nach irgendeinem der Ansprüche 9 bis 13, mit einem Indiumphosphidsubstrat.
16. Laser nach irgendeinem der vorangehenden Ansprüche, wobei der Laser eine Betriebslängenwelle zwischen 1,3 und 1,55 μm aufweist.
17. Laser mit verteilter Rückkopplung, in dem für eine optische Rückkopplung ein Raster (6) vorgesehen ist, wobei sich die optische Kopplung des Rasters entlang dessen Länge ändert und keine abrupten Änderungen des Kopplungsgrads über die Länge des Rasters auftreten, der Kopplungsgrad ist an oder nahe



der Mitte des Rasters (6) maximal und verläuft langsam auf Null, nahe zumindest einem der Enden des Rasters.

Patentansprüche für folgenden Vertragsstaat : GB

- 5 1. Halbleiterlaser mit verteilter Rückkopplung, der ein Indiumphosphidsubstrat aufweist, wobei die Mittel (6), welche die für den Laserbetrieb notwendige Rückkopplung vorsehen, über einen Hauptabschnitt der Länge des Lasers verteilt sind und sich das durch die Mittel (6) vorgesehene Rückkopplungsniveau über den Hauptabschnitt ändert, mit einem Maximum an oder nahe der Mitte der Mittel und einem Verlauf gegen
10 Null, nahe zumindest einem der Enden des Hauptabschnitts.
2. Laser nach Anspruch 1, in dem in Verwendung im wesentlichen die gesamte optische Rückkopplung in der Vorrichtung durch die Mittel (6) vorgesehen ist.
- 15 3. Laser nach Anspruch 1 oder 2, in dem sich der über den Hauptabschnitt vorgesehene Rückkopplungsbetrag ohne abrupte Änderungen ändert.
4. Laser nach einem beliebigen der vorangehenden Ansprüche, in dem die Mittel (6) ein Raster enthalten.
- 20 5. Laser nach Anspruch 4, in dem die Veränderung des durch die Mittel (6) vorgesehenen Rückkopplungsniveaus das Ergebnis einer Eigenschaft des Rasters ist, die sich entlang der Länge des Rasters ändert.
6. Laser nach Anspruch 5, in dem die sich ändernde Rastereigenschaft die Zahntiefe ist.
- 25 7. Laser nach Anspruch 5, in dem die sich ändernde Rastereigenschaft der Zahnabstand ist.
8. Laser nach Anspruch 5, in dem die Zahntiefe und der Zahnabstand des Rasters geändert werden.
9. Laser nach irgendeinem der Ansprüche 4 bis 8, in dem sich das Raster entlang im wesentlichen der gesamten Länge des Lasers erstreckt.
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10. Laser nach irgendeinem der vorangehenden Ansprüche, mit zumindest einer Facette (18, 19), die antireflexionsbeschichtet ist und eine Reflektivität von 1 % oder weniger bei einer Betriebswellenlänge der Vorrichtung aufweist.
- 35 11. Laser nach irgendeinem der vorangehenden Ansprüche, in dem das Raster durch eine Oberfläche einer Wellenführungsschicht (5) gebildet ist, wobei der Laser zusätzlich eine Aktivschicht (4) aufweist und Veränderungen der Dicke und/oder Breite der Wellenführungsschicht (5) zu der Rückkopplungsveränderung führen.
- 40 12. Laser nach irgendeinem der vorangehenden Ansprüche, in dem der Laser einen Steghohleiteraufbau aufweist.
13. Laser nach irgendeinem der vorangehenden Ansprüche, in dem der Laser eine beerdigte Heterostruktur aufweist.
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14. Laser nach irgendeinem der vorangehenden Ansprüche, wobei der Laser eine Betriebslängenwelle zwischen 1,3 und 1,55 μm aufweist.
- 50 15. Laser mit verteilter Rückkopplung, in dem für eine optische Rückkopplung ein Raster (6) vorgesehen ist, wobei sich die optische Kopplung des Rasters entlang dessen Länge ändert und keine abrupten Änderungen des Kopplungsgrads über die Länge des Rasters auftreten, der Kopplungsgrad ist an oder nahe der Mitte des Rasters (6) maximal und verläuft langsam auf Null, nahe zumindest einem der Enden des Rasters.



Revendications

Revendications pour les Etats contractants suivants : AT, BE, CH, DE, DK, ES, FR, GR, IT, LI, LU, NL, SE

- 5 1. Laser à réaction répartie dans lequel le moyen (6) qui procure la réaction nécessaire au fonctionnement du laser est réparti sur toute une partie principale de la longueur du laser, le niveau de réaction procuré par ledit moyen (6) varie sur toute ladite partie principale, présente un maximum au milieu ou à proximité du milieu dudit moyen et tend vers zéro à proximité d'au moins l'une des extrémités de ladite partie principale.
- 10 2. Laser selon la revendication 1 dans lequel, en utilisation, pratiquement toute la réaction optique à l'intérieur du dispositif est procurée par ledit moyen (6).
- 15 3. Laser selon la revendication 1 ou la revendication 2, dans lequel la quantité de réaction procurée sur toute ladite partie principale varie sans modifications brutales.
- 20 4. Laser selon l'une quelconque des revendications précédentes dans lequel le moyen (6) comprend un réseau de diffraction.
- 25 5. Laser selon la revendication 4, dans lequel la variation de niveau de réaction procurée par ledit moyen (6) résulte d'une propriété du réseau de diffraction qui varie tout au long du réseau de diffraction.
- 30 6. Laser selon la revendication 5, dans lequel la propriété du réseau de diffraction qui varie est la profondeur de dentelure.
- 35 7. Laser selon la revendication 5, dans lequel la propriété du réseau de diffraction qui varie est l'espacement de dentelure.
- 40 8. Laser selon la revendication 5, dans lequel la profondeur de dentelure et le pas de dentelure du réseau de diffraction varient tous les deux.
- 45 9. Laser selon l'une quelconque des revendications 4 à 8 dans lequel le réseau de diffraction s'étend pratiquement le long de toute la longueur du laser.
- 50 10. Laser selon l'une quelconque des revendications précédentes, dans lequel le laser comprend un laser à injection à semi-conducteur.
- 55 11. Laser selon la revendication 10, comportant au moins une facette optique (18, 19) qui est revêtue d'antireflet et qui présente une réflectivité à une longueur d'onde de fonctionnement du dispositif de 1 pour-cent ou moins.
12. Laser selon la revendication 9 ou la revendication 10 telles qu'elles dépendent de la revendication 3, dans lequel le réseau de diffraction est formé sur une surface d'une couche de guidage d'onde (5), le laser comprenant en outre une couche active (4), les variations de l'épaisseur et/ou de la largeur de la couche de guidage d'onde (5) résultant en ladite variation de réaction.
13. Laser selon l'une quelconque des revendications 9, 10 ou 11, dans lequel le laser comporte une structure de guide d'onde nervuré.
14. Laser selon l'une quelconque des revendications 9 à 12, dans lequel le laser comprend une hétérostructure enterrée.
15. Laser selon l'une quelconque des revendications 9 à 13, comprenant un substrat de phosphore d'indium.
16. Laser selon l'une quelconque des revendications précédentes, le laser présentant une longueur d'onde de fonctionnement entre 1,3 et 1,55 μm .



17. Laser à réaction répartie dans lequel un réseau de diffraction (6) est procuré afin de fournir une réaction optique, le couplage optique du réseau de diffraction varie avec la position sur sa longueur, il n'y a aucune variation brutale dans le degré de couplage sur la longueur du réseau de diffraction, le degré de couplage présente un maximum au milieu ou à proximité du milieu du réseau de diffraction (6), et le couplage tend régulièrement vers zéro à proximité d'au moins l'une des extrémités du réseau de diffraction.

Revendications pour l'Etat contractant suivant : GB

1. Laser à semi-conducteur à réaction répartie comprenant un substrat de phosphore d'indium dans lequel le moyen (6) qui procure la réaction nécessaire pour le fonctionnement du laser est réparti sur toute une partie principale de la longueur du laser, le niveau de réaction procuré par ledit moyen (6) varie sur ladite partie principale, présente un maximum au milieu ou à proximité du milieu dudit moyen et tend vers zéro à proximité d'au moins l'une des extrémités de ladite partie principale.
2. Laser selon la revendication 1 dans lequel, en utilisation, pratiquement toute la réaction optique à l'intérieur du dispositif est procurée par ledit moyen (6).
3. Laser selon la revendication 1 ou la revendication 2, dans lequel la quantité de réaction procurée sur ladite partie principale varie sans modifications brutales.
4. Laser selon l'une quelconque des revendications précédentes dans lequel le moyen (6) comprend un réseau de diffraction.
5. Laser selon la revendication 4, dans lequel la variation de niveau de réaction procurée par ledit moyen (6) résulte d'une propriété du réseau de diffraction variant tout au long du réseau de diffraction.
6. Laser selon la revendication 5, dans lequel la propriété du réseau de diffraction qui varie est la profondeur de dentelure.
7. Laser selon la revendication 5, dans lequel la propriété du réseau de diffraction qui varie est l'espacement de dentelure.
8. Laser selon la revendication 5, dans lequel la profondeur de dentelure et le pas de dentelure du réseau de diffraction varient tous les deux.
9. Laser selon l'une quelconque des revendications 4 à 8 dans lequel le réseau de diffraction s'étend pratiquement le long de toute la longueur du laser.
10. Laser selon l'une quelconque des revendications précédentes, présentant au moins une facette optique (18, 19) qui est revêtue d'antireflet et qui présente une réflectivité à une longueur d'onde de fonctionnement du dispositif de 1 pour-cent ou moins.
11. Laser selon l'une quelconque des revendications précédentes, dans lequel le réseau de diffraction est formé sur une surface d'une couche de guidage d'onde (5), le laser comprenant en outre une couche active (4), les variations de l'épaisseur et/ou de la largeur de la couche de guidage d'onde (5) résultant en ladite variation de réaction.
12. Laser selon l'une quelconque des revendications précédentes, dans lequel le laser comporte une structure de guide d'onde nervuré.
13. Laser selon l'une quelconque des revendications précédentes, dans lequel le laser comporte une hétérostructure enterrée.
14. Laser selon l'une quelconque des revendications précédentes, le laser présentant une longueur d'onde de fonctionnement entre 1,3 et 1,55 μm .
15. Laser à réaction répartie dans lequel un réseau de diffraction (6) est procuré pour fournir une réaction optique, le couplage optique du réseau de diffraction varie avec la position suivant sa longueur, il n'y a



aucune variation brutale dans le degré de couplage sur toute la longueur du réseau de diffraction, le degré de couplage présente un maximum au milieu ou à proximité du milieu du réseau de diffraction (6), et le couplage tend régulièrement vers zéro à proximité d'au moins l'une des extrémités du réseau de diffraction.

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