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(56) Documents Cited:
US 6842467 B1 **US 4372644 A**
US 20050089070 A1 **US 20020118904 A1**

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Other: **Online:WPI, EPODOC, INSPEC**

(54) Abstract Title: **Semiconductor laser**

(57) The semiconductor laser 104 package includes a small quarter wave plate 102 arranged on the optical axis of the laser device and in close proximity to the output facet of the laser. The polarisation state of the light emitted by the laser is rotated by 45° any retro-reflected laser light is also rotated by a further 45°. The 90° change in the polarisation state of the retro-reflected light reduces interferometric sub-cavity effects and also reduces light amplitude phase coupling which can cause emission coherence collapse. When the laser package incorporating the quarter wave plate is coupled to an optical fibre the optical isolation of the laser with respect to the back reflected light from the partially reflecting surface of the optical fibre is improved.

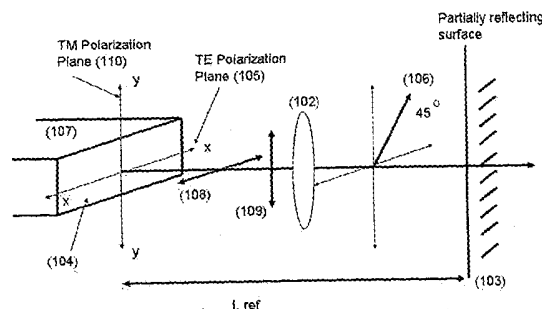


Figure 5

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 2007.

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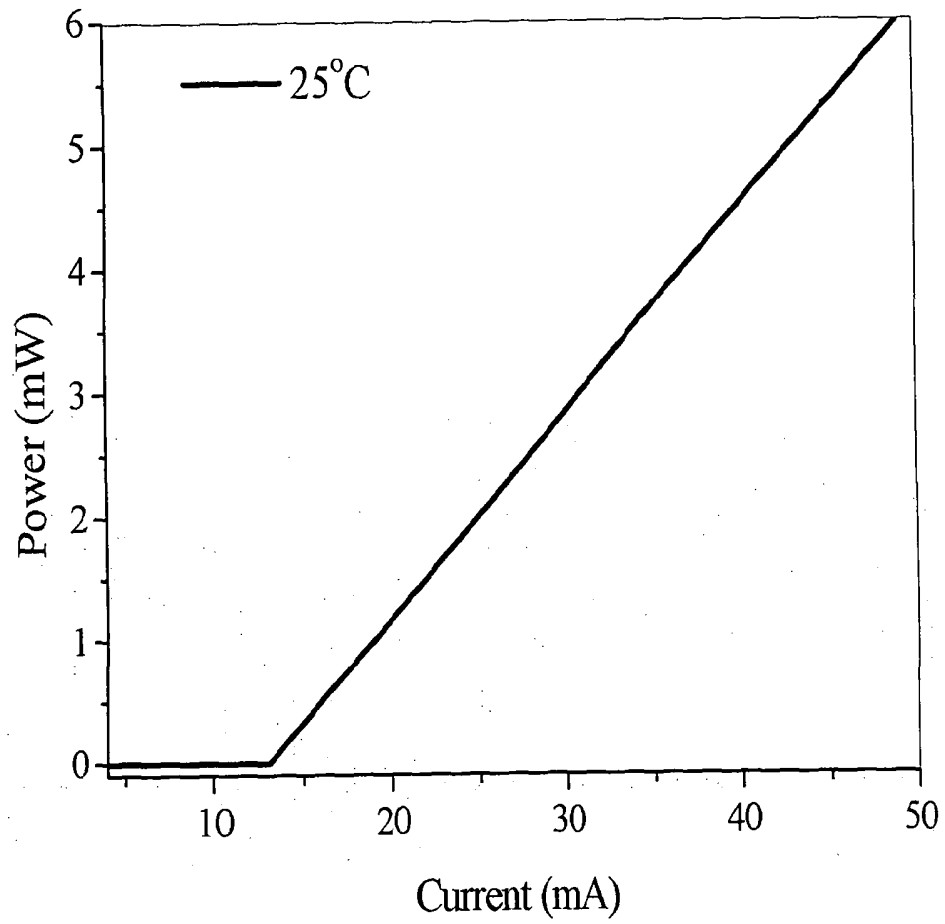


Figure 1.

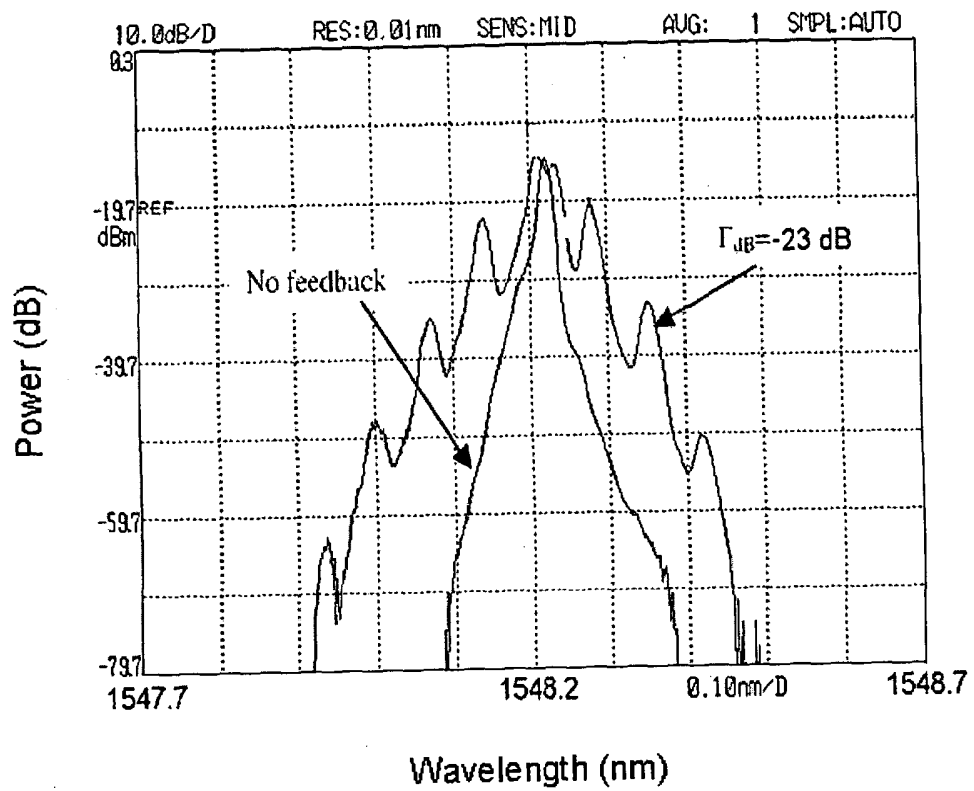


Figure 2

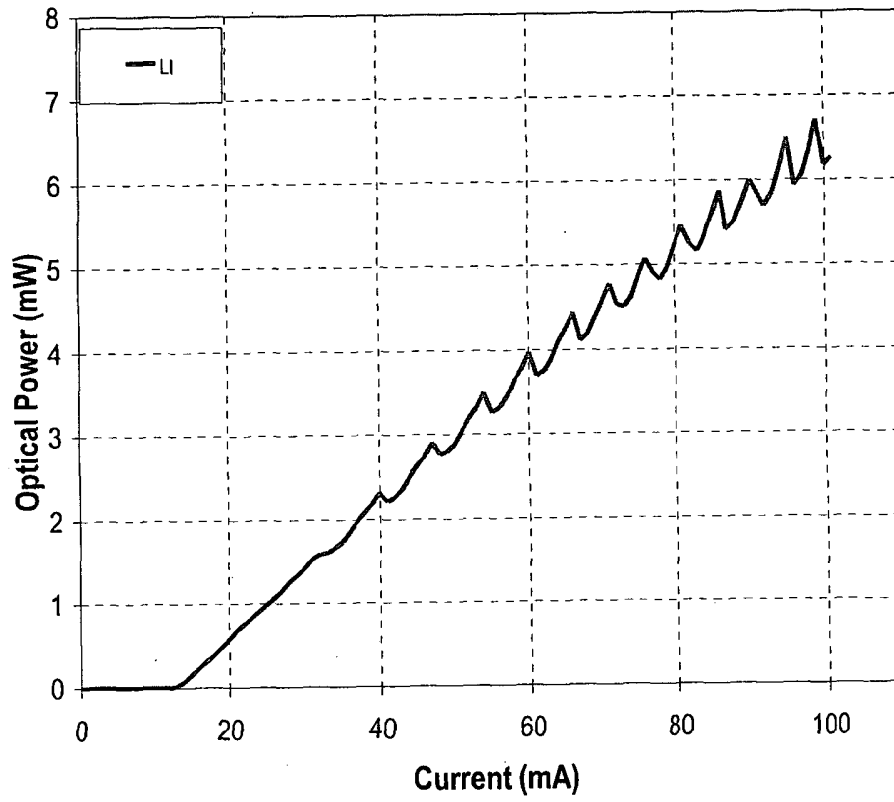


Figure 3.

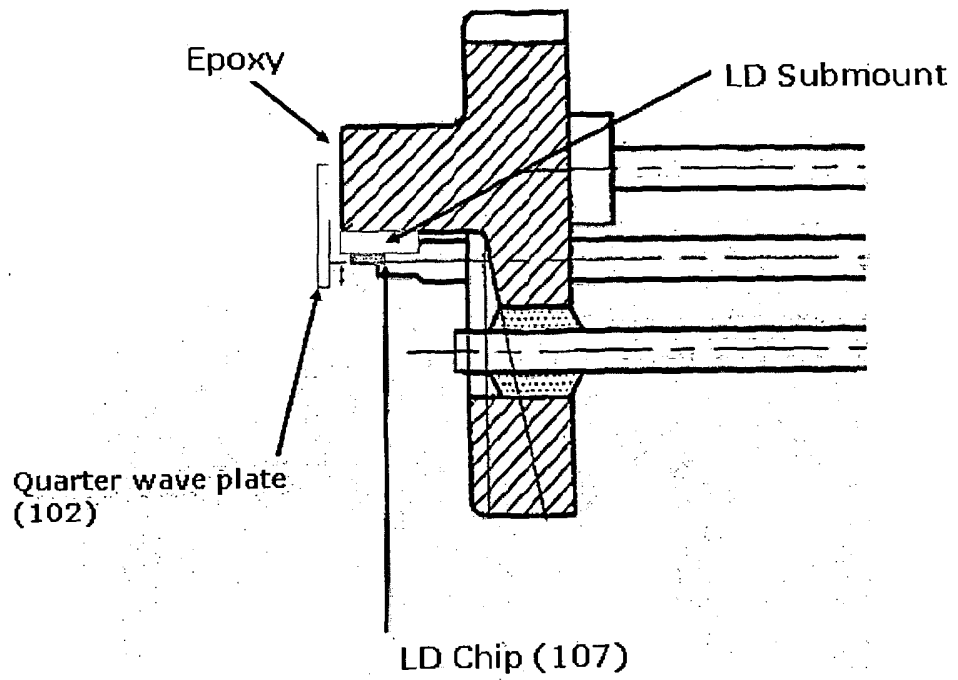


Figure 4

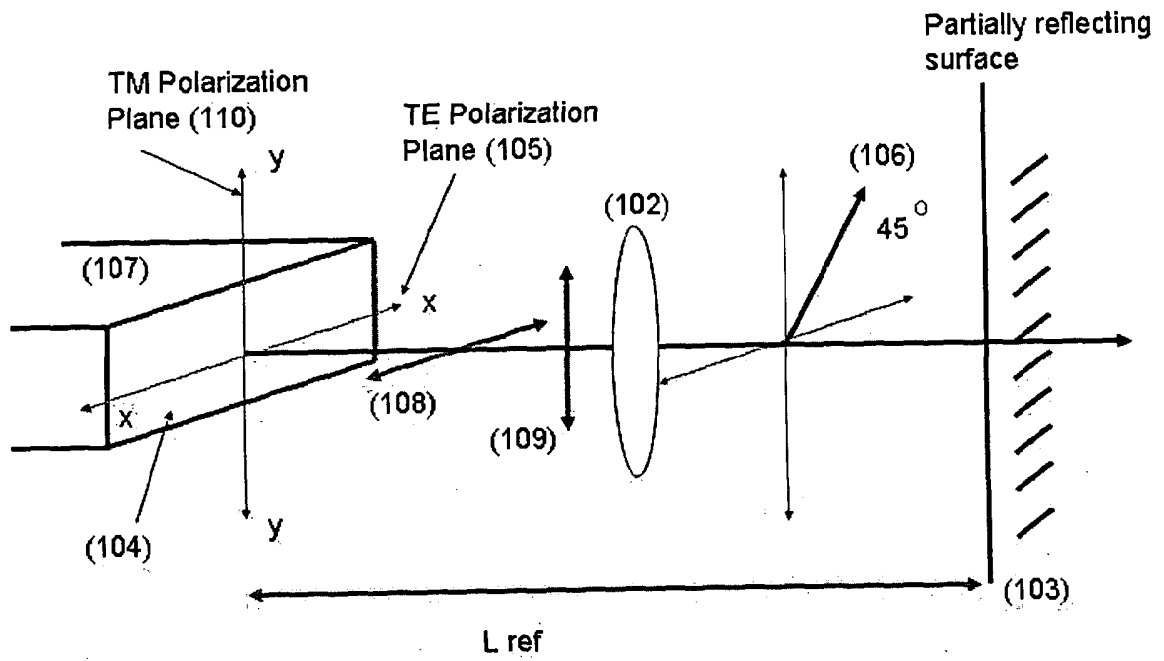


Figure 5

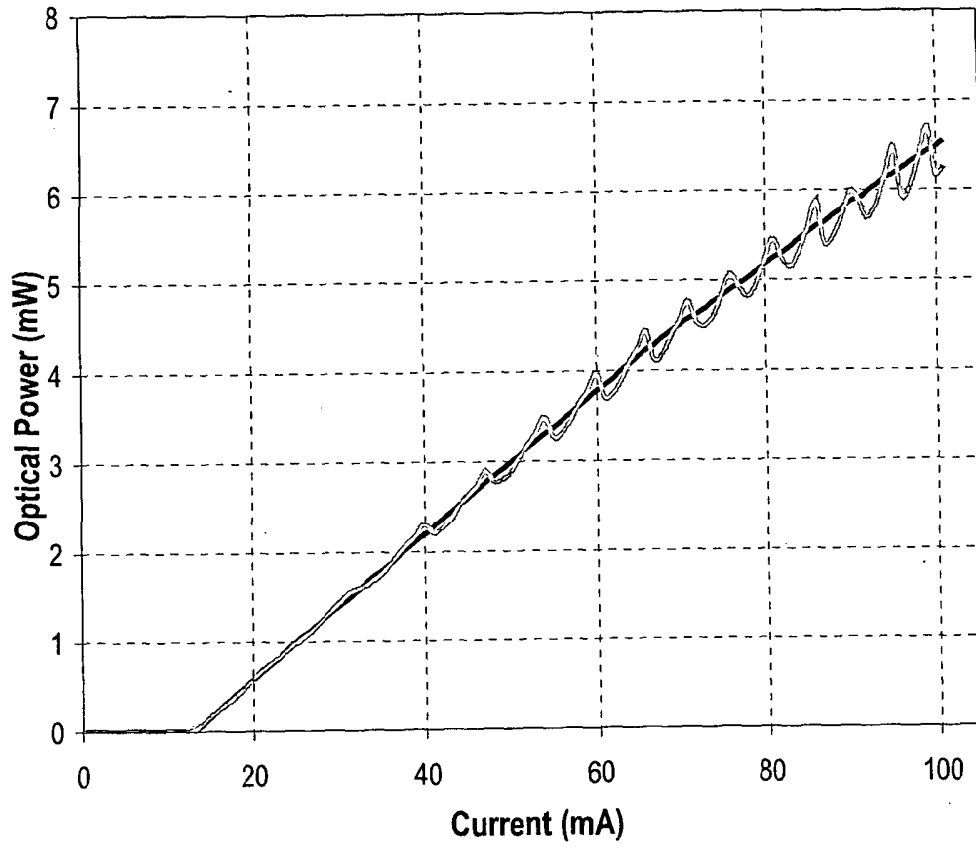


Figure 6.

A METHOD OF PACKAGING A LASER DIODE

FIELD

5 The present application relates to single wavelength laser diodes and in particular the simple low-cost packaging of said single wavelength laser diodes which eases the exploitation of the single-mode nature of the laser emission.

BACKGROUND

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For many applications back-reflection of the light emitted by a laser diode into the laser active region has a significant, negative, impact on the performance of the laser. Under some conditions the back-reflection leads to spectral line narrowing and under other conditions it can lead to unstable operation making the laser
15 emission unsuitable for use in many applications such as optical communications, sensing and metrology and Test and Measurement (Ref Tcatch and Chaprilvy) but also enabling others such as data storage .

For the purposes herein, light fed back into the laser diode can be grouped into two
20 classes: reflection from distant reflectors where the distance between the laser

emitting facet and the reflector (L_{ref}) is greater than the coherence length of the laser emission (L_{coh} ; $= c/\Delta\nu$, where c is the speed of light and $\Delta\nu$ is the laser linewidth in Hz) and secondly when $L_{ref} < L_{coh}$. In the former case the laser instability has two components: an interferometric effect due to the coherent summation of the light emitted by the laser with the back-reflected light and secondly a nonlinear dynamic effect due to the large carrier density / index of refraction coupling that exists in inverted semiconductor media.

For light reflected from distant reflectors, $L_{ref} > L_{coh}$ the interferometric effect is

absent and the refractive index / carrier density coupling dominates. On the basis of these considerations, there have been proposed many methods to isolate the laser gain medium from reflected light. To date these methods have been complex and expensive to implement and have restricted use of single wavelength laser diodes in many applications.

Accordingly a low cost method of packaging single mode laser diodes that substantially reduced the impact of reflected light on the laser performance would be beneficial.

SUMMARY

In summary, the present application relates to the simple low-cost packaging of a semiconductor laser which reduces the impact of reflected light on the

- 5 semiconductor laser operation so as to permit exploitation of the single mode nature of the laser emission in the presence of reflected light.

In one embodiment, a method of packaging a laser diode is provided comprising the step of placing a small quarter wave plate close to the emitting facet of the laser diode so that light emitted from the facet passes through the quarter wave plate.

- 10 The result of this is that the emission properties of the laser are substantially unaffected by light reflected from surfaces close to the emitting facet of the laser chip.

- These needs and others will be met by the present application which is set out in
15 detail in the description and/or claims which follow. The objects, features and advantages will become apparent from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The application will now be described in greater detail having regard to the accompanying drawings in which:

Figure 1 is a graph of the measured light current characteristics of a typical single mode laser diodes in the absence of optical feedback.

Figure 2 shows overlaid measured spectra illustrating the impact of feedback on the emission spectrum of a single mode DFB laser diode. The figure shows a substantially smooth spectrum obtained in the absence of optical feedback and a broader spectrum with many features resulting from emitted light being retroflected into the laser. (The feedback level was approximately -23dB).

Figure 3 is a graph of the measured light current characteristics of a DM single mode laser diode in the presence of optical feedback where a portion of the emitted light is retroflected into the laser, in this case from a cleaved fibre endface close to the laser chip resulting in a highly kinked characteristic. (Otherwise the operation conditions are as in Figure 1).

Figure 4 Schematic diagram of a typical TO can laser package modified so that a quarter wave plate is interposed close to the laser chip.

Figure 5 Schematic diagram illustrating the impact of a quarter wave plate on the polarization state of the propagating laser light after emission from the

laser , before and after reflection by the reflector and after two transits through the quarter wave plate.

Figure 6 is a graph of the measured light current characteristics of a DM single

mode laser diode in the presence of optical feedback where a small

5 portion of the emitted light is retroflected into the laser from a cleaved fibre endface positioned close to the laser and a properly oriented

quarter waveplate is interposed between the laser and the reflector.

For illustrative purposes the kinked light current characteristic of Figure

3 is also shown in the Figure (Otherwise the operation conditions are as

10 in Figures 1 and 3).

DETAILED DESCRIPTION OF THE INVENTION

Known single-mode lasers suffer from the problem of their emission sensitivity to reflected light as described previously. Firstly, light reflected from nearby surfaces
5 can create interferometric based instabilities due to the formation of interacting Fabry-Perot etalons by the reflecting surface (103) and the emitting facet of the laser (104). Secondly instabilities also arise from the fact that the laser diode optical cavity length, $L_{opt} = nL$, is influenced by the presence or absence of reflected light (n is the average index of refraction of the laser diode waveguide and L is the physical
10 length of the chip). While a wide range of phenomenology has been observed and are well known and discussed in the literature (for example R. W. Tkach and A. R. Chraplyvy) two distinct cases are to be made . Firstly where $L_{ref} < L_{coh}$ and secondly where $L_{ref} > L_{coh}$ and the symbols have the same meanings as previously.

15 When $L_{ref} > L_{coh}$ the instabilities which arise are due to interaction between the Fabry-Perot cavity formed by the laser chip and the Fabry-Perot formed by the the emitting facet of the laser 104 and the reflecting surface 103. In the case where $L_{ref} > L_{coh}$ the instabilities which arise are primarily due to the second (highly nonlinear) effect where coupling between the index of refraction / optical carrier density /

electromagnetic field phase shift lead to spectral instability and substantial accompanying laser intensity noise.

DFB laser diodes are single mode lasers well known and understood by those skilled
5 in the art. DFB lasing emission is strongly affected by both effects which necessitates
the use of bulky complex and expensive Faraday isolators to prevent optical
feedback. DM lasers diodes are also well known and understood by those skilled in
the art but show a lesser sensitivity to light reflected from distant reflectors in their
operation.

10 It is an object of the current application to eliminate or alleviate feedback noise that
either results from interferometric originated mode competition (and selection) or
instabilities that arise from the nonlinear interaction between the lasing mode
supported by the semiconductor waveguide and cavity and the reflected light field.

15 It is a further object of the current application to eliminate or alleviate feedback
noise using a minimum of components ancillary to the laser package itself.

It is a yet a further object of the current application to isolate the laser diode chip from reflected light using a minimum of components ancillary to the laser package itself.

- 5 It is a final object of the current application to isolate the laser diode chip from reflected light using low cost a low cost approach which does not require sensitive mechanical alignments and can be readily and cheaply implemented applied at all laser diode emission wavelengths.
- 10 Figure 1 shows the Light versus Current (Lvl) characteristic of a single-mode DM laser diode in the absence of retro-reflected light. The Lvl is highly linear and does not display kinks. In Figure 2 the smooth single peaked emission spectrum of a singlemode DFB laser in the absence of feedback(Figure 2, no feedback) shows lasing is occurring into a single narrow wavelength (mode of the laser cavity). Figure 2 also
- 15 shows the optical spectrum where feedback of $\Gamma_{db} = -23\text{dB}$ of the DFB laser emission is retro-reflected into the laser. The spectrum in this case has multiple peaks and is significantly broadened. In contrast the Lvl characteristic of Figure 3 shows the impact of light retro- reflected from the flat endface of of a single mode fibre on the emission of a DM laser. The Lvl shows shows clear nonlinearity and kinks. It is well
- 20 understood by those skilled in the art that lasers exhibiting such characteristics are

unsuited for their main target applications due to their excessive emission intensity noise and non-constant emission spectra. (The multi-peaked spectrum of Figure 2 when feedback is present is actually due to the time averaging by the spectrum analyzer of the single laser mode wavelength which is fluctuating in time.)

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Conventionally the sensitivity of DFB lasers to retro-reflected light is addressed by interposing in the laser package an optical subassembly which permits throughput of light in one direction only. A typical optical isolator subassembly consists of two polarization elements (a polarizer and an analyzer having a 45° differential in the direction of their light transmission axes), and of a 45° Faraday rotator interposed between the polarization elements. A forward light passing the optical isolator undergoes the following: (1) when passing through the polarizer, the incident light is transformed into a linearly polarized light; (2) when passing through the Faraday rotator, the polarization plane of the now linearly polarized light is rotated through 45°; (3) this light passes through the analyzer without loss since its polarization plane is now in the same direction as the light transmission axis of the analyzer, which is tilted 45° from the polarizer in the direction of Faraday rotation. In contrast, backward reflected light undergoes a different process: (1) when passing through the analyzer, the backward light is transformed into a linearly polarized light with an initial 45° tilt in the transmission axis; (2) when passing through the Faraday rotator,

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the polarization plane of the backward light is now rotated a further 45° in the same direction as the initial tilt; (3) this light is consequently completely shut out by the polarizer because its polarization plane is now 90° away from the light transmission axis of the polarizer.

5

Polarization-dependent faraday isolators are primarily incorporated in semiconductor laser modules. Accordingly, miniaturization is an important aspect of the design. To realize this objective, the polarizing beam splitter is replaced by a lower cost infrared polarizing glass as a polarization element. Nonetheless Faraday isolators use exotic and expensive material for their proper operation: Bismuth substituted iron garnet films are used as Faraday rotators due to their low saturation magnetization and large rotation capacity while strong rare-earth magnets such as the Samarium-Cobalt type are often employed to apply the required large magnetic field to the Faraday rotator. The performance of optical isolators is primarily evaluated by their insertion losses and isolations, both of which are determined by the absorption losses end-face reflectances, and the extinction ratios of the polarizing optical elements used.

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This conventional approach suffers from a number of significant problems (i) cost, (ii) alignment sensitivity (iii) sensitivity of operation to coatings of optical

subcomponents (iv) throughput and loss and finally (v) size. All of these factors have led to the Faraday isolator solution to be economically feasible only in high cost optical subassemblies used in low volume niche applications.

- 5 Even in diode lasers with bulk active regions (REF Chuang) a significant asymmetry in the lasing emission polarization arises due to the higher optical confinement factor and hence lower threshold current of the Transverse Electric (TE) waveguide mode in comparison to that of the Transverse Magnetic (TM) mode which consequently has a higher threshold current . In laser diodes with quantum well active regions the
- 10 lifting of the degeneracy of the light hole and heavy hole valence bands due to the large differences in the quantum confined state energies of the light and heavy holes leads to large differences in their absorption and emission cross-sections. As a result the recombination between the electron in the conduction band and the light hole in the valence band (the origin of TE emission) dominates in quantum well lasers.
- 15 Strain in the active region, as is often used in compressively strained quantum well lasers to improve aspects of laser performance. This slightly reduces the heavy-hole light / hole splitting, and hence slightly reduces the laser materials' intrinsic polarization recombination asymmetry. Nonetheless the combination of these intrinsic polarization asymmetries in the optical constants of the materials with the
- 20 greater TE confinement factor discussed previously leads to enhancement of the

asymmetry in the emission polarization to an extent where even for compressively strained layer quantum well laser diodes emission is almost entirely in the TE polarization state and absorption and gain in the TM polarization are to all intents and purposes negligible.

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Figure 4 shows a schematic diagram of an exemplary embodiment of this application employing a quarter wave plate while Figure 5 shows a schematic diagram

illustrating the impact of a quarter wave plate on the polarization state of the propagating laser light after emission from the laser, before and after reflection by

10 the reflector (103) and after two transits through the quarter wave plate (102). A laser diode chip (107) with emission predominantly in a single polarization state (here for convenience taken as the TE polarization state) is mounted in proximity to a quarter wave plate element (102) the optical axis of which is oriented such that the polarization plane of light emitted from the laser chip is rotated to a plane (106)

15 which is oriented at 45° from the emission plane of polarization of (105) of the laser chip. This light upon retro-reflection by the reflector (103) and retransmission through the quarterwave plate is rotated by a further 45° . This retroreflected light upon being incident on the chip facet is now polarized (109) at 90° from the emitting polarization state (108) and corresponds to the TM polarized plane (110) of the laser
20 waveguide into which it is coupled.

This 90° change in the polarization state has two main impacts. Firstly
interferometric sub-cavity effects are reduced and secondly light amplitude phase
coupling leading to emission coherence collapse is also reduced due to the
5 polarization asymmetries of the quantum well materials.

Figure 6 shows the impact of imposing a quarter wave plate in the fashion described
between the laser and the fiber cleaved end face of Figure 1 for the same operating
conditions. It is obvious from the measured data that the impact of the light
10 reflected from proximate reflectors on the laser emission is reduced to negligible
levels. The LVI has returned to smooth linearity and for comparison purposes the
kinked LVI which is measured in the the absence of the quarter wave plate is shown
for comparison.

15 It is useful to place this application in context with prior art. It is well known to those
experienced in the field that strong optical isolation against accidentally reflected
light is required for use of single mode lasers in many applications particularly where
good coupling efficiency to optical fibres or instruments and systems are required.
Conventionally Faraday rotators are used as rotators of the polarization state due to
20 their continuous rotation of the polarization state of the light field. Unfortunately

such systems require use of a discrete polarizer to select a polarization state launched from the laser and a separate analyzer to also restrict the back-reflected light to a single polarization state. This leads to polarization selective losses (since light which is retro-reflected in the subassembly is lost if in the incorrect

5 polarization). This can be overcome by use of expensive bi-refrangent crystals as polarizers and analyzers.

The use of such a complicated expensive system is required since the light launched into a fibre has its polarization state randomized due to light scattering in the optical
10 fibre. Consequently retro-reflected light can be in any polarization state when retroreflected and when it is incident on the isolator subassembly must therefore pass through an appropriately oriented polarizer before being incident on the rotator and analyzer.

15 In the current application a number of key elements contribute to its usefulness.

Firstly the high polarization anisotropy of the optical processes in strained layer quantum well lasers leads to a reduced impact on the stability of the lasing mode of retro-reflected light rotated to a polarization state perpendicular to that emitted by the laser. Secondly the compound cavity effects which arise from the coherent
20 summation of emitted and retro-reflected light when $L_{\text{ref}} < L_{\text{coh}}$ are suppressed

because of the orthogonality in polarization of the interfering beams. Finally, since DM lasers are Fabry-Pérot laser diodes modified by surface etchings so as to lase in a single Fabry-Pérot mode of the cavity (i.e. they are a mode selected Fabry-Pérot laser diode) they are highly insensitive to those instabilities that arise when $L_{ref} >$

5 L_{coh} in which case the instabilities which arise are primarily due to nonlinear coupling between the index of refraction / optical carrier density and electromagnetic field phase shifts. Consequently for the DM laser any residual feedback to the laser chip in the TE mode arising from polarization state randomizing due to scattering in the fibre does not impact the DM laser performance in single-mode applications. It is for
10 this reason that the quarter wave plate has such unobvious efficacy in use as an optical isolator.

Consequently the simple expedient of inserting a properly placed quarter wave plate in proximity to the laser chip facet and between the laser chip and any retro-
15 reflector provides in practice sufficient immunity to optical feedback for application where currently more complex and expensive optical isolator are required.

While in the description of the invention above reference has been only made to a TO-can package, those skilled in the art will recognize that the method can be

applied to other package types including but not exclusively : silicon optical benches,
planar lightwave circuits and butterfly packages.

REFERENCES

5

R. W. Tkach and A. R. Chraplyvy, "Regimes of feedback effects in 1.5 μm distributed
feedback lasers," *J. Lightw. Technol.*, vol. LT-4, no. 11, pp. 1655-1661, Nov. 1986.

Chuang, S.L.; O'Gorman, J.; Levi, A.F.J.; Quantum Electronics, IEEE Journal

10 of, Volume 29, Issue 6, June 1993 Page(s):1631 – 1639

CLAIMS

1. A method of packaging a laser diode comprising the step of placing a small
quarter wave plate close to the emitting facet of the laser diode so that light
5 emitted from the facet passes through the quarter wave plate.
2. The method of Claim 1 where the laser diode lases in substantially a single
mode .
- 10 3. The method of Claim 1 where the laser diode is a DFB laser.
4. The method of Claim 1 where the laser diode is a DM laser.
5. The method of Claim 1 where the packaged laser diode is used as a signal
15 source for digital optical communications
6. The method of Claim 5 where the laser diode is used as a signal source for
Gigabit Passive Optical Networks (GPON).

7. The method of Claim 1 where the packaged laser diode is used as a signal source for Optical Datacomms

8. The method of Claim 7 where the laser diode is used as a signal source for Internet Protocol (IP) based communications.

9. The method of Claim 1 where the packaged laser diode is used as a signal source for sensor and test and measurement applications.

10.The method of Claim 9 where the packaged laser diode is used as a signal source for sensor optically pumped atomic and microwave clocks.

11.The method of Claim 9 where the packaged laser diode is used as a signal source for trace gas sensing

12.The method of Claim 1 where the packaged laser diode is used as a signal source for coherent optical communications.

13.The methods of claims 2-15 where the laser package is a TO can

14. The methods of claims 2-15 where the laser package is a silicon optical bench

15. The methods of claims 2-15 where the laser package is a planar lightwave circuit.

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16. A laser assembly comprising:

a laser diode for emitting light along an optical axis,

a quarter wave plate element positioned along said optical axis.

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17. A laser assembly according to claim 16, wherein the laser diode is adapted to provide a polarized light.

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18. A laser assembly according to claim 17, wherein the quarter wave plate element is arranged such that the polarization plane of the light emitted from the laser diode is rotated to a plane which is oriented in the range of 40° to 50° (preferably about 45°) from the emission plane of polarization of the laser diode.

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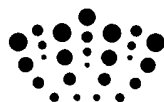
19. A laser assembly according to anyone of claims 16 to 18, wherein the laser diode is a single mode laser diode.

20. A laser assembly as claimed in claim 17, wherein that the quarter wave plate element the optical axis is oriented such that the polarization plane of the light emitted from the laser diode is rotated to a plane which is oriented about 45° from the emission plane of polarization of the laser diode.

5

21. A laser assembly as claimed in anyone of claims 16 or 20, further comprising an optical element positioned along the optical axis and configured to receive light from the laser, wherein in use the optical element at least partially reflects the light from the laser, with the polarization plane of this reflected light being rotated by 45° as it passes through the quarter wave plate.

10



Application No: GB0814273.9

Examiner: Mr Steven Morgan

Claims searched: all

Date of search: 5 December 2008

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-21	US2002/0118904 A1 (MAN) See paragraphs 11-14.
X	1-17	US4372644 A (UNGER) See line 20, column 2 - line 37, column 6
X	1-17	US6842467 B1 (ARONSON) See figures 7B & 7C & lines 27-59 column 6.
X	1-17	US2005/0089070 A1 (HONDA) Note paragraph 88 in particular.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X:

Worldwide search of patent documents classified in the following areas of the IPC
G02B; H01S
The following online and other databases have been used in the preparation of this search report
Online:WPI, EPODOC, INSPEC

International Classification:

Subclass	Subgroup	Valid From
H01S	0005/022	01/01/2006
G02B	0006/42	01/01/2006