

Description

The present invention relates to optical amplification, in particular to absorptive non-linearity and bistability in laser diodes.

Absorptive bistable lasers are known, and they have been used for experimental purposes. In one such known device, an InGaAsP buried heterostructure laser diode has its upper contact layer split into two electrically isolated portions, and each portion can be differently biased. One portion is subjected to a bias current sufficient to cause operation above the laser threshold, whilst the other is biased so that little injection current flows. This second portion acts as a non-linear saturable absorber. It was found that, at suitable temperatures and with the first portion initially biased at fractionally below threshold (eg 99% of threshold), optical or electrical pumping to above the lasing threshold causes non-linearity and bistability with, in some cases, large hysteresis effects. Relatively high bias currents, typically to far above threshold, are required. Details of practical work and theoretical calculations for absorptive bistability in semiconductor injection lasers have been published by a number of researchers. A useful review of the subject is given in J. Optical & Quantum Electronics, Vol. 19, (1987) S1-36, H. Kawaguchi.

In this specification, the term "non-linear" is used to refer to a device or its operation where there is, at some point, a jump in output for given operating conditions. "Bistability" is an enhanced non-linear effect (i.e. the non-linearity is more pronounced) where there is hysteresis. At the onset of bistability there is a region of instability, where there are small bistable effects and frequent switches in output may arise (self-pulsation) due to very small unintended operating or environment changes (e.g. temperature).

Absorptive bistable lasers can be made to lase by optical pumping to above threshold at any wavelength within the gain spectrum although of course optical pumping on a Fabry-Perot mode will be inefficient. Whatever pumping wavelength is chosen, lasing (with the laser resonating at the wavelength where the Q of the laser cavity is highest) occurs at the device's lasing wavelength (defined by the peak of the gain curve). Normal lasers have multiple longitudinal emission modes at several wavelengths, and hence will give a multimode output at the peak of the gain curve, and this is often a disadvantage. DFB lasers with absorptive regions have therefore been used to overcome this problem and provide single mode operation. DFB or other narrow band lasers tend to be expensive, which is a disadvantage.

The present invention provides a new and advantageous non-linear optical device and mode of operation.

First, it has been found that it is not necessary to initiate lasing (ie resonance) for non-linear effects to

arise. Surprisingly, the same degree of non-linearity arises even below threshold; so the same proportional increase in output (ie level of bistability) can be achieved by operating the device as an amplifier rather than a laser. Typically, the amplifier may be both initially biased and subsequently operated at about 10-20% below the threshold bias.

Furthermore, one is not limited to output at the lasing wavelength defined by the peak of the gain curve. For any input at a wavelength within the gain spectrum, an amplified output is obtained at the same wavelength. Thus, there is a wide choice of output wavelengths. Also, it is not necessary to use an expensive narrowband laser, such as a DFB laser, for the device with saturable absorber, since with this invention monomode output from the device is obtained whenever the input to the device is monomode. It has also been found that in those devices with significantly reflective facets lower switching energies are obtained by tuning the input wavelength to the peak of a Fabry-Perot mode in the gain spectrum for the device.

The present invention provides a method of amplifying an optical signal, the method comprising the steps of locating an optical amplifier device having an amplification region and a saturable absorption region arranged so that the device is capable of resonating and so that an optical input signal of selected wavelength λ is receivable by the amplification region; pumping the amplification region to below the lasing threshold of the device; the input optical signal impinging on one of said regions via the other of said regions; operating the device in a non-linear manner such that the optical output signal non-linearly depends on the optical input signal and has a bistable operational characteristic; and receiving via said one region an amplified output at the input wavelength λ , characterised in that the input optical signal is at such a wavelength, and the amplification region is pumped to a level of 5% or more below the lasing threshold of the device, that laser oscillation is avoided.

The device may comprise an input facet, through which the optical signal is input into said one region, and an output facet for the outputting of said amplified output, the device including means to reduce the reflectivity of the facets. The reflectivity of each of facets may be 20% or less, preferably 10% or less, more preferably 3% or less, and yet more preferably 1% or less.

The invention also provides an optical amplifier of the type having a lasing threshold, and partially reflective facets, the amplifier comprising an amplification region, a saturable absorption region, and means for inputting an optical signal of selected wavelength λ_1 into one of said regions via the other of said regions, the device being such as being to operate in a non-linear manner such that the optical output signal non-linearly depends on the optical input signal so that an

amplified optical output with a bistable output characteristic at wavelength λ_1 is generated, characterised in that the amplifier further comprises means adapted to pump the amplification region to a maximum value of 95% of the lasing threshold such that laser oscillation of the device is avoided.

For an understanding of the present invention and its significance, it is important that the differences between laser amplification and laser oscillation be well understood. Laser oscillation occurs in lasers, that is those devices in which a material with gain is positioned within an optical resonator, laser oscillation only taking place if there is a sufficiency of both gain and feedback. For any resonator construction, the lasing threshold ("threshold") defines the pumping limit above which laser oscillation will take place. Laser amplification occurs in devices where there is gain but where the combination of gain and feedback is sufficiently low for resonance not to occur. Consequently, a laser amplifier which has feedback may, if pumped hard enough (optically or electrically) start to oscillate and hence change from being an amplifier to being a laser. The change from amplifying operation to operation as a laser results from pumping above threshold. It is possible to pump both a laser oscillator ("laser") and a laser amplifier optically. The pump wavelength may in both cases have a wavelength which is shorter than the short wavelength limit of the gain spectrum. The pump wavelength may alternatively be within the gain curve, although if the pump wavelength coincides with a Fabry-Perot mode of the laser there will be little absorption and hence little if any pumping there will however be amplification.

An optical input (within the gain curve or with a shorter λ) can cause either one of two things to happen; it can either be absorbed or it can be amplified. If the optical input is absorbed, there is optical pumping and hence carriers will be excited. Excitation of carriers will increase spontaneous emission. As spontaneous emission rises the absorber will start to saturate. When the absorber has saturated, the device will resonate at the peak of the gain curve (that is, it will lase).

If the optical input is amplified, the carrier density is reduced, but the density of the photons is increased. Increasing the photon density incident on the absorber will eventually cause the absorber to saturate, and the output will switch. Hence, when amplifying, the device has switched output without the device being taken over threshold (and hence without lasing).

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

Figure 1 is a view of an embodiment of a device according to the present invention;

Figure 2 is a graph of output power vs amplifier

bias under various conditions, for the device of Figure 1;

Figure 3 is a sketch of an arrangement of components including the device of Figure 1;

Figure 4 is a graph of switching threshold vs frequency for bistable operation and Figure 4(a) is a sample transfer characteristic;

Figure 5 is a spectrum at the output of the device of Figure 1 when it is operating bistably;

Figure 6 is a typical gain spectrum for a device of the type shown in Figure 1;

Figure 7 is a transfer characteristic and pulse shaping effect obtainable when the device of Figure 1 is operated non-linearly;

Figure 8 shows transfer characteristics for a range of input powers for the device of Figure 1 operated non-linearly when the absorber region is biased; and

Figure 9 and 10 show further examples of device structures.

Referring to Figure 1, there is shown a long wavelength diode 11, which is an InGaAsP buried heterostructure laser diode, with active area dimensions of $0.15 \times 1.6 \times 400 \mu\text{m}$ and a confinement factor of 0.3.

The device has an upper p contact layer which is split into two electrically isolated portions 13, 15 (associated with sections 14, 16 of the device) by a photolithographically controlled wet etching process. The separation between the two portions is $10 \mu\text{m}$, giving a resistance between the two Au/Ti metallisation portions of typically about 450 Ohms. Portion 13 is $120 \mu\text{m}$ long and portion 15 is $270 \mu\text{m}$ long. The whole device is mounted on a Peltier cooler (not shown) and the temperature of the device is adjustable by varying the temperature of the cooler using a platinum resistor (not shown).

Respective gold bond pads 17, 19 are pressure bonded onto the Au/Ti metallisation on portions 13, 15, so that the two ends of the device can be differentially biased.

Section 14 remains unbiased during operation, and thus the active layer at this end of the device acts as a non-linear saturable absorber. The saturable absorption region absorbs radiation at the frequency at which it would, under different circumstances, emit. Only a finite amount of radiation is absorbed, and the region therefore saturates, thereafter providing no further absorption. Prior art publications, such as the article by Kawaguchi referred to above, explain in quantum mechanical terms how a fabricated device with one or more absorber regions acts when one contact portion is biased at the threshold level and the other is unbiased.

Figure 2 is a graph showing this known mode of operation. Output power is plotted against amplifier bias current for a variety of temperatures of the Peltier cooler. Note that at 291K, there is non-linear emission above the threshold (16mA). At 299K there is an un-

stable region at threshold, and at 312K the first hysteresis effects are visible, with full hysteresis effects at 325K. The bistability becomes more pronounced as temperature is increased further. At very much higher temperatures, non-linearity disappears, as gain falls with increasing temperatures, and absorption increases. It will be appreciated that optical, instead of electrical, power can be used for biasing. For example, it may be convenient to bias electrically to threshold, and use optical power for switching in the bistable (hysteresis) region. Control over the characteristics may be achieved by varying bias (optical or electrical or both) as well as (or instead of) temperature.

We have discovered that the device can be biased and operated below the lasing threshold, and that non-linearity and bistability are still observable even with a small forward bias on the absorber. Reverse biasing the absorber increases speed by decreasing the recovery time of the absorber. However, the amount of reverse bias which can be applied is limited by the resistance between the contacts associated with the portions 13 and 15, excessive reverse bias results in a surface leakage current across the gap between the electrodes. An arrangement of components used for operation according to one embodiment of the invention is illustrated in Figure 3. The results of operation at a range of modulation frequencies of the input light intensity are shown in Figure 4. A sample transfer characteristic (10MHz triangular input wave) is shown in the inset.

Referring to Figure 3, a DFB laser 21 provides optical input at $1.556\mu\text{m}$. The input is tunable over 2nm by adjusting the laser's operating temperature. Laser 21 is isolated from device 11 using a tailed Faraday rotation isolator 23, with an isolation of 35dB. A tapered, lensed fibre 25 is used to couple light from laser 21 via a polarisation controller 27 to the TE mode in the amplifier section 16, which is biased at a selected value (40mA in this example) which is below threshold (45mA). The output of unbiased absorber section 14 is coupled via a second tapered, lensed fibre to a detector 29. Detector 29, which is a $30\mu\text{m}$ PIN photodiode with a bandwidth of 13.5GHz, is connected via two amplifiers (not shown) to a sampling oscilloscope 31.

The response of device 11 to an optical input while biased below the lasing threshold (45mA) for a range of modulation frequencies is shown in Figure 4. With the device operating bistably, at 335K, the output of the device 11 switches from a low state of $8\mu\text{W}$ to a high state of $35\mu\text{W}$ at the input wavelength of $1.556\mu\text{m}$, with rise time of around 200ps. The width of the hysteresis, expressed by the difference in bias current between the top and bottom of the hysteresis step, was 1mA. As a result, a sine wave input is converted into a square wave output. By locating a 1nm band pass filter 33 tuned to the emission wavelength

of laser 21 (not shown) between device 11 and detector 29, the low state is reduced to $1\mu\text{W}$ and the high state to $30\mu\text{W}$ (an extinction ratio of 15dB). A sample transfer characteristic (10 MHz triangular wave) is shown in Figure 4(a).

The speed of switching of device 11 when operated as a bistable optical amplifier biased well below threshold is limited by the recovery time of the absorber region. As explained above, reverse biasing the absorber region decreases the recovery time of the absorber. Maximum switch repetition rate is about 0.25GHz.

With the absorber section 14 completely unbiased the maximum switch repetition rate is limited to about 0.25GHz. It has been discovered that by positively biasing the absorber region slightly, the width of the hysteresis decreases and, with bias of about 0.6mA in the absorber region, the device loses its bistability and becomes simply non-linear. Another effect is that recovery time decreases. This is discussed in more detail below, when non-linear operation is described.

As the device 11 has reflective facets, minimum switching power is achievable by tuning the input to the peak of one of the devices Fabry-Perot modes. Figure 5 is a mode spectrum for device 11 showing mode peaks 41 and troughs. By selecting a peak, improved gain and a lower switching threshold are obtainable. The response of device 11 depends on the modulation frequency, but by tuning to a peak of one of the Fabry-Perot modes, the best possible gain is achieved. With this particular device, an output power of about $36\mu\text{W}$ was achieved, while the minimum power required to change state was $2\mu\text{W}$ and at the maximum repetition frequency of 150MHz the threshold for repeated state changes was $36\mu\text{W}$ (note these are not pulse energies). Thus the net gain of the amplifier varied between 0 and 12dB for bistable operation (unsaturated gain). The gain is much lower and the switching threshold much higher than for a device operated above the lasing threshold, but the extinction ratio is unchanged.

If the bias current is reduced from 40mA, but the temperature maintained at 335K, (threshold is 45mA), the hysteresis is reduced and the switching threshold increases. With a bias current of 25mA, the switching threshold was $100\mu\text{W}$; $100\mu\text{W}$ was the maximum power obtainable from the input laser 21 and hence it was not possible to determine switching thresholds for lower bias currents.

The input wavelength from the input laser 21 may be any suitable wavelength compatible with device 11. For this particular device, the range of possible wavelengths is around 30nm, centered at the lasing wavelength, $1.57\mu\text{m}$. Typically, the range is 30-50nm centered on the lasing wavelength. One important feature of the device operated below the threshold is that the incident light is amplified, so the output light

has the same wavelength (or spread of wavelengths) as the input. With a DFB laser input, a useful single mode output is obtainable.

In contrast, if operated above threshold, the device operates as a wavelength shifter, and the output is always at the lasing wavelength (and will be multi-mode even with input light from a DFB laser, if device 11 is constructed as a multi-mode laser).

As illustrated in Figure 6, for a device with facet reflectivities of 0.08%, at well below threshold (70% of threshold), the gain spectrum is relatively flat with only a small amount (3dB) of residual ripple, so a wide range of wavelengths may be amplified and tuning is relatively easy. At higher bias (95%) the spectrum is more peaked (about 10dB here), its 3dB width is narrower, and the mode bandwidth is reduced. This trend applies to all laser amplifiers regardless of the reflectivity of their facets, and the optimum operating point is always a compromise between the available gain and the required bandwidth. For an input signal to be amplified, the bandwidth of the input signal must be less than the bandwidth of the Fabry-Perot peaks. Additionally, the variability of the centre frequency of the input signal combined with the input signal bandwidth must be less than the width of the Fabry-Perot modes. Hence if the Fabry-Perot modes are narrow, one needs to control the centre frequency of the input signal and there is a limit on the transmission bandwidth. The best trade-off for most purposes is obtained at about 70% of threshold, where the gain is reasonable, the range of wavelengths which may be amplified is acceptably wide, and tuning is easy.

As explained above, the input wavelength needs to be tuned, for best gain, to a peak of the mode spectrum for device 11. This may be achieved by tuning the source with a grating for example, or by varying its temperature by adjusting the temperature of the Peltier cooler. Well below the device threshold, the mode peaks are broader, with lower peak to trough ratios, so less accurate control is needed to tune to a mode peak.

The operation of the device 11 in the bistable region has been described above. Operation at lower temperatures, in the region of non-linearity only without hysteresis effects (referred to here as simple non-linearity), will now be described. One application for the device 11 operated below threshold in the simple non-linear regime is for reshaping and amplifying of pulses. One example of the pulse shaping effect obtainable is shown in Figure 7(b). The transfer characteristic is shown in Figure 7(a). The sinusoidal input pulse is shown in the upper part of Figure 7(b) and the reshaped square wave output is shown below. The precise shape of the output can be varied by altering the temperature or bias of the absorber section 14 - raising the bias to decrease the absorption or raising the temperature to increase absorption (but not so high as to introduce bistable effects).

Thus, in the simple non-linear regime, the device is useful as a regenerative amplifier. Other applications of the device are as an optical limiter, as a pulse compressor, and as a low noise amplifier.

It has been explained above that by biasing the absorber region when the device is operating in the bistable regime, the device loses its bistability. One example of the use of the device of Figure 1 with a biased absorber region will now be given. The amplifier 11 is operated at 18°C with 16mA bias in the amplifier region 16 and 0.6mA bias in the absorber section 14. The optical transmitter 21, as before, is a DFB laser, aligned with a peak of the gain curve of amplifier 11. Other circuit details are as before.

A sample transfer characteristic of the device 11 for a triangular wave input is shown in Figure 8. This characteristic is strongly non-linear (but not bistable) and the non-linearity has a detector limited risetime of 200ps. The maximum repetition rate is 1-4GHz for non-linear operation, compared to 0.25GHz maximum switching rate with bistable operation. The non-linearity is dependent on the optical gain and is thus dependent on the detuning between the input wavelength and the Fabry-Perot modes of device 11. In general, detuning the input to shorter wavelengths results in a reduction in gain and a reduction in the optical output power, as already explained. The minimum input power required for non-linear gain was -51dBm and the minimum input power for a contrast ratio of 10dB was -30dBm. The maximum input modulation frequency at which pulse shaping occurred was 700MHz, corresponding to a minimum repetition time of 700ps.

Figures 9 and 10 show alternative device structures. In the Figure 9 embodiment, there are three electrode portions 51, 53 and 55. Portions 51 and 53 are biased at several mA, but below the device threshold, and portion 53 is zero biased, or biased to a small extent, for example at below 1mA, thereby creating a saturable absorber section 57. Portions 51, 53 may be differentially biased for additional control.

The device structure shown in Figure 10, in which the amplification region and the absorption region are defined by a "zig-zag" gap there between, is particularly advantageous. With such a structure, the length and/or area available for mounting a bonding pad for the absorption region is/are increased. Since the absorption region is short, possibly as short as 15µm, conventional arrangements are difficult to bond to. Of course, it is not essential that the gap between the contact layers of the two regions crosses the active layer waveguide perpendicularly as shown, but the arrangement shown is particularly convenient.

As many electrode portions as desired may be provided - in fact the absorber and amplifier regions may be distributed along the length of the device alternately, in a stripe pattern, as shown schematically

in Figure 11. We have found that while such structures can be used according to the invention, their performance is generally worse than that of the simple devices such as that described with reference to Figure 1. In particular, we have found that devices with distributed absorption and amplifier regions have higher thresholds and lower switching speeds than those of Figure 1 type devices. If such "distributed" devices are fabricated the amplifier regions may be about twice as long as absorption regions. The absorption regions may be doped so that they cannot be biased, whilst the amplifier regions can be biased - for example zinc may be diffused into these regions to provide conductivity.

The ratio of absorption region to amplifying region may be selected depending on the desired characteristics, as may the total length of the device. For InGaAsP, device length may conveniently be in the range 200-500 μ m for uncoated devices (reflectivity typically 30%). The absorption region is generally noticeably shorter than the amplifier region - say in the ratio 2:3 to 1:3. An unduly long absorption region (or long total length if there is distributed absorption) would restrict the non-linearity - if the absorption exceeds the gain in the amplifying region, the absorber does not saturate and non-linear effects are not seen.

The spacing between differently biased regions needs to be chosen with some care. In the Figure 1 example, the spacing was about 10 μ m and the inter-contact resistance 400 Ohms. If the resistance is too low, then the non-linear properties are lost, as bias leaks into the absorber, and absorption is reduced. On the other hand, if the gap is too big, loss is introduced between the two regions as the result of waveguide loss from the exposed active layer, effectively reducing the gain.

As mentioned above, the reflectivities of the two ends of the device are conveniently, if uncoated, about 30% (a typical laser reflectivity). These are advantages in reducing the reflectivities of the device facets. In general, as one reduces the facet reflectivities the transmission bandwidth increases, the amount of hysteresis reduces and the maximum switching rate increases. However, within these general rates, we have found that the amount of hysteresis falls with falling facet reflectivities, and that 3% reflectivity appears to be a limiting value below which there is simple non-linearity and no hysteresis. Also, while the maximum switching rate increases with falling facet reflectivities, there appears to be a limit about 0.5%, below which the maximum switching rate is constant.

When operated as a switch, the switch rise time is also dependent on facet reflectivity. With reflectivities below about 0.1%, the rise time is determined by the length of the absorber zone. With an absorber length of about 120 μ m, and facet reflectivities below 0.1%, the rise time is about 2ps, while for higher re-

flectivity facets the rise time is slower.

Repetition time is a function of the rise time and the fall time, the fall time being limiting. Fall time has two components: one, as in rise time, is a change in photon density; the other is recovery time of the absorber. As facet reflectivity falls, a shorter absorber is needed for the same degree of absorption. Photon lifetime falls as reflectivity falls, and hence changes in photon density are quicker and hence rise time and fall time both decrease. The use of a shorter absorber also results in shorter recovery times.

Pulse compression can also be achieved with devices operated according to the present invention, the minimum output pulse width which can be achieved depending on the facet reflectivities. The Minimum achievable pulse width depends upon the photon lifetime in the device and upon the bandwidth of the gain within the device. In general, reducing the facet reflectivities also reduces the minimum achievable pulse width, although the relationship is not simply linear. For low reflectivities, that is about 1%, the photon lifetime is the limiting factor in determining minimum pulse width. For example, with a facet reflectivity of 0.5%, the device of Figure 1 would have a photon lifetime of about 7ps and the minimum achievable pulse length would be about 10ps. Such a device, receiving an input optical pulse of length 20ps, would output an optical pulse of only 10ps. As facet reflectivity is increased, for an otherwise fixed system the photon lifetime increases.

For reflectivities above about 1%, the gain bandwidth becomes an increasingly important factor. With uncoated facets having a minimum pulse duration of about 100ps. With 3% reflectivity the Figure 1 device would have a minimum pulse duration of about 20ps.

One major advantage of operating devices as described below threshold is the good wavelength control over the output - essentially the output has the same wavelength or range of wavelengths as the input. The input wavelength may be any selected wavelength within the gain curve. This overcomes one of the major disadvantages of devices operated above threshold where a selected wavelength within a permissible range could be input, but for any given device, only a single output is possible at the lasing wavelength. This output, for most current lasers, is multimode, although DFB devices may enable monomode output to be achieved. The present invention avoids such difficulties, as only a narrow band source (such as DFB laser 21) is required for a narrow band output.

A further significant advantage of devices operating according to the present invention is that they can be used for low noise amplification. Since the devices have a low (essentially zero) output when there is no optical input, only switching on when there is an optical input, in the absence of an optical input, there is, unlike the situation with conventional laser ampli-

fiers, no output due to spontaneous emission in the amplifier. This is of a particular advantage where the amplifier is being used to boost the output of a transmitter, because it usefully reduces the degradation of signal to noise ratio at the front end of a system.

Reducing the reflectivity of the output facet without similarly reducing the reflectivity of the input facet will tend to increase the output contrast ratio.

Reducing the reflectivity of the input facet is useful in maintaining bistability over a wide range of input signal bandwidths.

Various useful effects are realisable with devices in which the input facets and the output facets have different reflectivities.

Claims

1. A method of amplifying an optical signal, the method comprising the steps of locating an optical amplifier device (11) having an amplification region (16) and a saturable absorption region (14) arranged so that the device is capable of resonating and so that an optical input signal of selected wavelength λ is receivable by the amplification region; pumping the amplification region to below the lasing threshold of the device; the input optical signal impinging on one of said regions via the other of said regions; operating the device in a non-linear manner such that the optical output signal non-linearly depends on the optical input signal and has a bistable operational characteristic; and receiving via said one region an amplified output at the input wavelength λ , characterised in that the input optical signal is at such a wavelength, and the amplification region is pumped to a level of 5% or more below the lasing threshold of the device, that laser oscillation is avoided.
2. A method as claimed in claim 1, wherein said one region is the saturable absorption region (14).
3. A method as claimed in claim 1 or claim 2, wherein the amplification region (16) and the saturable absorption region (14) together are bounded so as to form an effective cavity, and wherein the input optical signal is tuned to a peak of a Fabry-Perot mode in the gain spectrum for the device.
4. A method as claimed in any one of claims 1 to 3, wherein the device (11) comprises an input facet through which the optical signal is input into said one region, and an output facet for the outputting of said amplified output, the device including means to reduce the reflectivity of the facets.
5. A method as claimed in claim 4, wherein the reflectivity of each of the facets is 20% or less.
6. A method as claimed in claim 5, wherein the reflectivity of each of the facets is 1% or less.
7. A method as claimed in any one of claims 4 to 6, wherein the input facet has substantially the same reflectivity as the output facet.
8. A method as claimed in any one of claims 4 to 6, wherein the input and output facets have substantially different reflectivities.
9. A method as claimed in any one of claims 1 to 8, further comprising the step of controlling the temperature of the device (11), and/or the bias of the amplification region (16), thereby to operate the device in said nonlinear manner.
10. A method as claimed in any one of claims 1 to 9, further comprising the step of varying the input wavelength so as to control the output wavelength.
11. A method as claimed in any one of claims 1 to 10, further comprising the step of controlling the device (11) so as to operate bistably.
12. An optical amplifier (11) of the type having a lasing threshold and partially reflective facets, the amplifier comprising an amplification region (16), a saturable absorption region (14), and means for inputting an optical signal of selected wavelength λ_i into one of said regions via the other of said regions, the amplifier being such as to operate in a non-linear manner such that the optical output signal non-linearly depends on the optical input signal so that an amplified optical output with a bistable output characteristic at wavelength λ_i is generated, characterised in that the amplifier further comprises means adapted to pump the amplification region to a maximum value of 95% of the lasing threshold such that laser oscillation of the device is avoided.
13. An optical amplifier as claimed in claim 12, wherein a first electrode (19) is provided for the biasing of the amplification region (16), a second electrode (17) is provided for the biasing of the saturable absorption region (14), and wherein the electrical resistance between said first and second electrodes is sufficiently high to enable the amplification region and the saturable absorption region to be differentially biased with a substantially lower voltage applied to the second electrode than to the first electrode.
14. An optical amplifier comprising a buried hetero-



flers, no output due to spontaneous emission in the amplifier. This is of a particular advantage where the amplifier is being used to boost the output of a transmitter, because it usefully reduces the degradation of signal to noise ratio at the front end of a system.

Reducing the reflectivity of the output facet without similarly reducing the reflectivity of the input facet will tend to increase the output contrast ratio.

Reducing the reflectivity of the input facet is useful in maintaining bistability over a wide range of input signal bandwidths.

Various useful effects are realisable with devices in which the input facets and the output facets have different reflectivities.

Claims

1. A method of amplifying an optical signal, the method comprising the steps of locating an optical amplifier device (11) having an amplification region (16) and a saturable absorption region (14) arranged so that the device is capable of resonating and so that an optical input signal of selected wavelength λ is receivable by the amplification region; pumping the amplification region to below the lasing threshold of the device; the input optical signal impinging on one of said regions via the other of said regions; operating the device in a non-linear manner such that the optical output signal non-linearly depends on the optical input signal and has a bistable operational characteristic; and receiving via said one region an amplified output at the input wavelength λ , characterised in that the input optical signal is at such a wavelength, and the amplification region is pumped to a level of 5% or more below the lasing threshold of the device, that laser oscillation is avoided.
2. A method as claimed in claim 1, wherein said one region is the saturable absorption region (14).
3. A method as claimed in claim 1 or claim 2, wherein the amplification region (16) and the saturable absorption region (14) together are bounded so as to form an effective cavity, and wherein the input optical signal is tuned to a peak of a Fabry-Perot mode in the gain spectrum for the device.
4. A method as claimed in any one of claims 1 to 3, wherein the device (11) comprises an input facet through which the optical signal is input into said one region, and an output facet for the outputting of said amplified output, the device including means to reduce the reflectivity of the facets.
5. A method as claimed in claim 4, wherein the reflectivity of each of the facets is 20% or less.
6. A method as claimed in claim 5, wherein the reflectivity of each of the facets is 1% or less.
7. A method as claimed in any one of claims 4 to 6, wherein the input facet has substantially the same reflectivity as the output facet.
8. A method as claimed in any one of claims 4 to 6, wherein the input and output facets have substantially different reflectivities.
9. A method as claimed in any one of claims 1 to 8, further comprising the step of controlling the temperature of the device (11), and/or the bias of the amplification region (16), thereby to operate the device in said nonlinear manner.
10. A method as claimed in any one of claims 1 to 9, further comprising the step of varying the input wavelength so as to control the output wavelength.
11. A method as claimed in any one of claims 1 to 10, further comprising the step of controlling the device (11) so as to operate bistably.
12. An optical amplifier (11) of the type having a lasing threshold and partially reflective facets, the amplifier comprising an amplification region (16), a saturable absorption region (14), and means for inputting an optical signal of selected wavelength λ_1 into one of said regions via the other of said regions, the amplifier being such as to operate in a non-linear manner such that the optical output signal non-linearly depends on the optical input signal so that an amplified optical output with a bistable output characteristic at wavelength λ_1 is generated, characterised in that the amplifier further comprises means adapted to pump the amplification region to a maximum value of 95% of the lasing threshold such that laser oscillation of the device is avoided.
13. An optical amplifier as claimed in claim 12, wherein a first electrode (19) is provided for the biasing of the amplification region (16), a second electrode (17) is provided for the biasing of the saturable absorption region (14), and wherein the electrical resistance between said first and second electrodes is sufficiently high to enable the amplification region and the saturable absorption region to be differentially biased with a substantially lower voltage applied to the second electrode than to the first electrode.
14. An optical amplifier comprising a buried hetero-



structure solid state diode (11) having a light signal passage channel, and first and second electrodes (19, 17) spaced apart by at least approximately 10µm longitudinally along and above the channel for applying different electrical bias currents to the diode at respectively located spaced-apart regions, thus defining a corresponding optical amplification region (16) under the first electrode and a saturable optical absorber region (14) under the second electrode; the diode having partially reflective facets of substantially less than 30% reflectivity located at opposite ends of the channel, between which facets the first and second electrodes are sequentially disposed; the diode further comprising means to bias the first electrode to a maximum level of 5% or more below the lasing threshold of the diode as to remain therebelow even when an input light signal pulse is received via one of the facets and causing the corresponding amplification region of the diode to operate as a non-linear light amplifier with a bistable operational characteristic; and the second electrode being conditioned to cause the saturable optical absorber region to act as a saturable light absorber when receiving light signals output from the amplification region just prior to outputting a processed light signal via the remaining one of the facets.

15. An optical amplifier as claimed in claim 14, wherein the first electrode (19) is at least approximately twice as long as the second electrode (17) along the channel.
16. An optical amplifier as claimed in claim 14 or claim 15, wherein there are no electrodes in addition to the first and second electrodes (19, 17) between the facets.
17. An optical amplifier as claimed in any one of claims 14 to 16, wherein the facets have reflectivities of substantially less than 10%.
18. An optical amplifier as claimed in claim 17, wherein one facet has a substantially higher reflectivity than the other facet.
19. An optical amplifier as claimed in any one of claims 14 to 18, further comprising means for controlling the wavelength of input light signals to correspond to a lasing mode of the diode (11) if it were to be biased above its lasing threshold.
20. An optical amplifier as claimed in any one of claims 14 to 17, wherein the electrodes (19, 17) are biased to cause bistable optical outputs from the amplifier.

Patentansprüche

1. Verfahren zum Verstärken eines optischen Signals mit den Schritten:
Anbringen eines optischen Verstärkerbauelements (11) mit einem Verstärkerbereich (16) und einem sättigbaren Absorberbereich (14), die so angeordnet sind, daß das Bauelement resonanzfähig ist, so daß ein optisches Eingangssignal von ausgewählter Wellenlänge λ vom Verstärkerbereich empfangen werden kann;
Pumpen des Verstärkerbereichs bis unter die Laserschwelle des Bauelements, wobei das optische Eingangssignal einen der Bereiche (14, 16) über den anderen der Bereiche erreicht;
Betreiben des Bauelements in nichtlinearer Weise, so daß das optische Ausgangssignal nichtlinear vom optischen Eingangssignal abhängt und eine bistabile Betriebskennlinie aufweist; und
Empfangen eines verstärkten Ausgangssignals bei der Eingangswellenlänge λ über besagten einen Bereich,
dadurch gekennzeichnet, daß
das optische Eingangssignal eine solche Wellenlänge hat, und der Verstärkerbereich auf ein Niveau von 5 % oder mehr unterhalb der Laserschwelle des Bauelements gepumpt wird, daß Laserschwingung vermieden wird.
2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß besagter einer Bereich der sättigbare Absorberbereich (14) ist.
3. Verfahren nach Anspruch 1 oder Anspruch 2, dadurch gekennzeichnet, daß der Verstärkerbereich (16) und der sättigbare Absorberbereich (14) verbunden sind, um einen wirksamen Hohlraum zu bilden, und daß das optische Eingangssignal auf eine Spitze einer Fabry-Perot-Mode im Verstärkungsspektrum des Bauelements abgestimmt ist.
4. Verfahren nach einem der Ansprüche 1 bis 3, dadurch gekennzeichnet, daß das Bauelement (11) eine Eingangsfensterfläche, durch die das optische Signal in besagten einen Bereich eingegeben wird und eine Ausgangsfensterfläche zur Ausgabe des verstärkten Ausgangssignals hat, wobei das Bauelement Mittel zum Verringern der Reflektivität der Fensterflächen umfaßt.
5. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß die Reflektivität einer jeden Fensterfläche 20 % oder weniger ist.



6. Verfahren nach Anspruch 5, dadurch gekennzeichnet, daß die Reflektivität einer jeden Fensterfläche 1 % oder weniger ist. 5
7. Verfahren nach einem der Ansprüche 4 bis 6, dadurch gekennzeichnet, daß die Eingangsfensterfläche im wesentlichen dieselbe Reflektivität wie die Ausgangsfensterfläche hat. 10
8. Verfahren nach einem der Ansprüche 4 bis 6, dadurch gekennzeichnet, daß Eingangs- und Ausgangsfensterflächen deutlich unterschiedliche Reflektivitäten haben. 15
9. Verfahren nach einem der Ansprüche 1 bis 8, mit dem weiteren Schritt des Steuerns der Temperatur des Bauelements (11) und/oder der Ruheenergieversorgung des Verstärkungsbereichs (16), um dadurch das Bauelement in besagter nichtlinearer Weise zu betreiben. 20
10. Verfahren nach einem der Ansprüche 1 bis 9, mit dem weiteren Schritt des Veränderns der Eingangswellenlänge, um so die Ausgangswellenlänge zu steuern. 25
11. Verfahren nach einem der Ansprüche 1 bis 10, mit dem weiteren Schritt des Steuerns des Bauelements (11) zum bistabilen Betrieb. 30
12. Optischer Verstärker (11) mit einer Laserschwelle und teilreflektierenden Fensterflächen, der einen Verstärkerbereich (16), einen sättigbaren Absorberbereich (14) und Mittel zum Eingeben eines optischen Signals von ausgewählter Wellenlänge λ in einen dieser Bereiche über den anderen dieser Bereiche umfaßt, wobei der Verstärker beschaffen ist, um in der Weise nichtlinear zu arbeiten, daß das optische Ausgangssignal nichtlinear vom optischen Eingangssignal abhängt, so daß ein verstärktes optisches Ausgangssignal mit bistabiler Ausgangskennlinie bei der Wellenlänge λ erzeugt wird, dadurch gekennzeichnet, daß der Verstärker Mittel umfaßt, die eingerichtet sind, um den Verstärkerbereich auf einen Maximalwert von 95 % der Laserschwelle zu pumpen, so daß Laserschwingung des Bauelements vermieden wird. 35 40 45 50
13. Optischer Verstärker nach Anspruch 12, bei dem eine erste Elektrode (19) zum Vorspannen des Verstärkerbereichs (16) vorgesehen ist, eine zweite Elektrode (17) zum Vorspannen des sättigbaren Absorberbereichs (14) vorgesehen ist, und bei dem der elektrische Widerstand zwischen der ersten und der zweiten Elektrode groß genug ist, um zu ermöglichen, daß der Verstärkerbereich und der sättigbare Absorberbereich differentiell vorgespannt werden, wobei an die zweite Elektrode eine deutlich niedrigere Spannung angelegt wird als an die erste Elektrode. 55
14. Optischer Verstärker mit einer Festkörperlaserdiode (11) mit vergrabener Heterostruktur, mit einem Lichtsignaldurchgangskanal und ersten und zweiten Elektroden (19, 17), die in einem Abstand von wenigstens ca. 10 μm in Längsrichtung des Kanals über diesem angeordnet sind, um unterschiedliche elektrische Ruhestrome an die Diode in jeweils beabstandet liegenden Bereichen anzulegen und so einen entsprechenden optischen Verstärkerbereich (16) unter der ersten Elektrode und einen sättigbaren optischen Absorberbereich (14) unter der zweiten Elektrode zu definieren; wobei die Diode an entgegengesetzten Enden des Kanals angeordnete teilreflektierende Fensterflächen mit einer Reflektivität von deutlich weniger als 30 % besitzt, zwischen welchen Fensterflächen die erste und zweite Elektrode nacheinander angeordnet sind; wobei die Diode ferner Mittel zum Vorspannen der ersten Elektrode auf ein maximales Niveau aufweist, das 5 % oder mehr unterhalb der Laserschwelle der Diode liegt, um auch dann unter dieser zu bleiben, wenn ein Eingangslichtsignalpuls über eine der Fensterflächen empfangen wird und den Betrieb des entsprechenden Verstärkerbereichs der Diode als nichtlinearer Lichtverstärker mit bistabiler Betriebscharakteristik verursacht; und die zweite Elektrode eingerichtet ist, um den Betrieb des sättigbaren optischen Absorberbereichs als sättigbarer Lichtabsorber beim Empfang von vom Verstärkerbereich ausgehenden Lichtsignalen unmittelbar vor dem Ausgeben eines verarbeiteten Lichtsignals über die verbleibende Fensterfläche zu bewirken.
15. Optischer Verstärker nach Anspruch 14, dadurch gekennzeichnet, daß die erste Elektrode (19) in Richtung des Kanals wenigstens ca. zweimal so lang wie die zweite Elektrode (17) ist.
16. Optischer Verstärker nach Anspruch 14 oder 15, dadurch gekennzeichnet, daß außer der ersten und zweiten Elektrode (19, 17) keine weiteren Elektroden zwischen den Fensterflächen vorhanden sind.
17. Optischer Verstärker nach einem der Ansprüche 14 bis 16, dadurch gekennzeichnet, daß die Fensterflächen Reflektivitäten von deutlich



unter 10 % haben.

18. Optischer Verstärker nach Anspruch 17, dadurch gekennzeichnet, daß eine Fensterfläche eine deutlich höhere Reflektivität als die andere Fensterfläche hat.

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19. Optischer Verstärker nach einem der Ansprüche 14 bis 18, gekennzeichnet durch Mittel zum Steuern der Wellenlänge von Eingangssignalen entsprechend einer Lasermode der Diode (11), wenn diese über ihre Laserschwelle vorgespannt würde.

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20. Optischer Verstärker nach einem der Ansprüche 14 bis 17, dadurch gekennzeichnet, daß die Elektroden (19, 17) vorgespannt werden, um bistabile optische Ausgangssignale des Verstärkers hervorzurufen.

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Revendications

1. Un procédé d'amplification de signaux optiques, le procédé comprenant les étapes consistant à positionner un dispositif amplificateur optique (11) qui inclut une région d'amplification (16) et une région d'absorption saturable (14) agencées d'une manière telle que le dispositif est susceptible de résonner et d'une manière telle qu'un signal optique d'entrée d'une longueur d'onde choisie λ est recevable par la région d'amplification; pomper la région d'amplification à un niveau inférieur au seuil d'effet laser du dispositif; le signal optique d'entrée frappant une première desdites régions en passant par l'autre desdites régions; mettre en oeuvre le dispositif d'une manière non linéaire afin que le signal optique de sortie dépende de façon non linéaire du signal optique d'entrée et présente une caractéristique opérationnelle bistable; et recevoir par l'intermédiaire de ladite première région une sortie amplifiée à la longueur d'onde d'entrée λ , caractérisé en ce que la longueur d'onde du signal optique d'entrée et le niveau de pompage, inférieur de 5% ou davantage au seuil d'effet laser du dispositif, de la région d'amplification sont tels qu'une oscillation laser est évitée.

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2. Un procédé selon la revendication 1, dans lequel ladite première région est la région d'absorption saturable (14).

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3. Un procédé selon la revendication 1 ou la revendication 2 dans lequel la région d'amplification (16) et la région d'absorption saturable (14) sont

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bornées l'une vis-à-vis de l'autre de façon à former une cavité effective, et dans lequel le signal optique d'entrée est accordé à une pointe d'un mode de Fabry-Pérot dans le spectre de gain du dispositif.

4. Un procédé selon l'une quelconque des revendications 1 à 3, dans lequel le dispositif (11) comprend une facette d'entrée à travers laquelle le signal optique est entré dans ladite première région, et une facette de sortie pour sortir ladite sortie amplifiée, le dispositif incluant un moyen de réduction de la réflectivité des facettes.

5. Un procédé selon la revendication 4, dans lequel la réflectivité de chacune des facettes est de 20% ou moins.

6. Un procédé selon la revendication 5, dans lequel la réflectivité de chacune des facettes est de 1% ou moins.

7. Un procédé selon l'une quelconque des revendications 4 à 6, dans lequel la réflectivité de la facette d'entrée est sensiblement la même que celle de la facette de sortie.

8. Un procédé selon l'une quelconque des revendications 4 à 6, dans lequel les réflectivités des facettes d'entrée et de sortie sont sensiblement différentes.

9. Un procédé selon l'une quelconque des revendications 1 à 8, comprenant en outre l'étape consistant à régler la température du dispositif (11), et/ou la polarisation de la région d'amplification (16) de manière à mettre ainsi en oeuvre le dispositif de ladite manière non linéaire.

10. Un procédé selon l'une quelconque des revendications 1 à 9, comprenant en outre l'étape consistant à faire varier la longueur d'onde d'entrée de façon à régler la longueur d'onde de sortie.

11. Un procédé selon l'une quelconque des revendications 1 à 10, comprenant en outre l'étape consistant à régler le dispositif (11) pour qu'il fonctionne de façon bistable.

12. Un amplificateur optique (11) du type à seuil d'effet laser et à facettes partiellement réfléchissantes, l'amplificateur comprenant une région d'amplification (16), une région d'absorption saturable (14) et un moyen d'entrer un signal optique d'une longueur d'onde choisie λ dans une première desdites régions en passant par l'autre desdites régions, l'amplificateur étant apte à



fonctionner d'une manière non linéaire de façon que le signal de sortie optique dépende d'une manière non linéaire du signal optique d'entrée, de façon que soit engendrée une sortie optique amplifiée à caractéristique de sortie bistable pour une longueur d'onde λ , caractérisé en ce que l'amplificateur comprend en outre un moyen apte à pomper la région d'amplification à une valeur maximale de 95% du seuil d'effet laser de sorte que l'oscillation laser du dispositif est évitée.

13. Un amplificateur optique selon la revendication 12, dans lequel une première électrode (19) est disposée de façon à polariser la région d'amplification (16), une deuxième électrode (17) est disposée de façon à polariser la région d'absorption saturable (14), et dans lequel la résistance électrique entre lesdites première et deuxième électrodes est suffisamment élevée pour permettre à la région d'amplification et à la région d'absorption saturable d'être polarisées de façon différentielle, la tension appliquée à la deuxième électrode étant sensiblement plus basse que celle qui est appliquée à la première électrode.

14. Un amplificateur optique comprenant une diode d'état solide (11) à hétérostructure enterrée incluant un canal de passage de signaux lumineux, et une première et une deuxième électrodes (19, 17) espacées longitudinalement d'au moins 10 μm le long du canal et au-dessus de celui-ci afin d'appliquer des courants électriques différents de polarisation à la diode à des régions respectivement situées à distance l'une de l'autre, en définissant ainsi une région correspondante d'amplification optique (16) sous la première électrode et une région d'absorbeur optique saturable (14) sous la deuxième électrode; la diode incluant des facettes partiellement réfléchissantes d'une réflectivité sensiblement inférieure à 30% à des extrémités opposées du canal, facettes entre lesquelles la première et la deuxième électrodes sont disposées en séquence; la diode comprenant en outre un moyen de polarisation de la première électrode à un niveau maximal inférieur de 5% ou davantage au seuil d'effet laser de la diode de façon à rester au-dessous de celui-ci même lorsqu'une impulsion de signal lumineux d'entrée est reçue par l'intermédiaire de l'une des facettes et amenant la région d'amplification correspondante de la diode à fonctionner sous forme d'amplificateur de lumière non linéaire à caractéristique opérationnelle bistable, et la deuxième électrode étant conditionnée de façon à amener la région d'absorbeur optique saturable à agir comme absorbeur saturable de lumière lorsqu'elle reçoit une sortie de signaux lumineux venant de la ré-

gion d'amplification immédiatement avant de sortir par l'intermédiaire de la facette restante un signal lumineux traité.

- 5 15. Un amplificateur optique selon la revendication 14, dans lequel la première électrode (19) est au moins approximativement deux fois plus longue que la deuxième électrode (17) le long du canal.
- 10 16. Un amplificateur optique selon la revendication 14 ou la revendication 15, dans lequel il n'existe, en plus de la première et de la deuxième électrodes (19, 17), aucune autre électrode entre les facettes.
- 15 17. Un amplificateur optique selon l'une quelconque des revendications 14 à 16, dans lequel la réflectivité des facettes est sensiblement inférieure à 10%.
- 20 18. Un amplificateur optique selon la revendication 17, dans lequel la réflectivité de l'une des facettes est sensiblement plus élevée que celle de l'autre facette.
- 25 19. Un amplificateur optique selon l'une quelconque des revendications 14 à 18, comprenant en outre un moyen de réglage de la longueur d'onde des signaux lumineux d'entrée pour qu'ils correspondent à un mode d'effet laser de la diode (11) si elle devait être polarisée au-delà de son seuil d'effet laser.
- 30 20. Un amplificateur optique selon l'une quelconque des revendications 14 à 17, dans lequel les électrodes (19, 17) sont polarisées de façon à provoquer des sorties optiques bistables à partir de l'amplificateur.
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