Stabilisation and control of widely tunable MG-Y lasers with integrated photodetectors

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Abstract: The control and stabilisation of a widely tunable modulated grating Y-branch (MG-Y) laser are discussed. A characterisation algorithm will be introduced, which produces for each standardised frequency a good operating point with a very small deviation from the wanted output frequency (± 2 GHz) and power (± 0.2 dB). In addition, a new stabilisation feedback scheme will be presented, which makes use of an external etalon for frequency stabilisation (a wavelength locker) and integrated photodetectors for mode stabilisation. This scheme guarantees that the laser continues operating at the wanted frequency even when the tuning sections degrade or when environmental conditions change. Thanks to those stabilisation algorithms, the lifetime of the device is greatly extended, in case of degrading tuning sections.

1 Introduction

Recently, there has been a trend in optical telecommunication networks using wavelength division multiplexing to start deploying widely tunable lasers. Those widely tunable lasers can help telecom operators worldwide to respond to the increasing bandwidth demand at a low price while introducing new functionality and higher flexibility in the network. At present, several widely tunable laser concepts have been presented (e.g. [1–5]), and many of them are DBR-type laser diodes with one or two passive reflector sections.

The control of those widely tunable lasers is rather complex (e.g. [6–9]) because two or more control currents have to be adjusted to obtain a certain frequency with a sufficient side mode rejection. However, the components are sold with an easy user interface in which the wanted frequency can be set by sending a simple digital command to a microprocessor. A tuning table is then used to convert the requested frequency into the right current values. The many variables make the creation of this tuning table very time-consuming. Additionally, fabrication tolerances cause a different tuning behaviour in each laser, so this characterisation needs to be done for each laser separately. Therefore a fast characterisation algorithm is needed to speed up this process and minimise the cost.

Tunable lasers degrade over time owing to the development and migration of defects within the semiconductor material [10]. These degradation effects, together with environmental changes, lead to a frequency drift and a decrease in the tuning efficiency, so feedback control strategies are needed to guarantee a reliable operation over time. Without a high frequency accuracy and high side-mode

suppression, the optical signals will be intermixed and fluctuating, leading to irrecoverable communication signals. A feedback mechanism that can counter the environmental influences and that postpones the re-calibration of the device with degrading tuning sections as long as possible is needed to make these devices commercially interesting.

For DBR-type lasers, the optimum operation points are those where a cavity mode is aligned with the reflection peaks. This can often be detected as an extremum in the output power versus the tuning current's characteristic. Unfortunately, the carrier-induced losses in the reflector sections may disrupt the output power extremum [6]. The voltage over the active section is a possible alternative: minimal voltage coincides with a high side-mode suppression because the carrier density increases when the reflector peaks are detuned from the cavity mode [7]. However, the previously mentioned methods cannot be used when the nonlinear effects are too high or when the wavelength selectivity of the roundtrip gain is not large enough.

The described mode stabilisation schemes are always used in combination with a wavelength locker for frequency stabilisation. Without such control and stabilisation algorithms, tunable laser diodes have to be very stable to be of commercial interest because the components need to be easy controllable and need to have a very stable output.

2 Operation principle of the MG-Y laser

The MG-Y laser was introduced a few years ago [1] as a new widely tunable laser diode with improved performance over other types.

A schematic of an MG-Y laser is shown in Fig. 1. Two reflectors with slightly different peak spacing are placed at the back. The reflected signals are added up coherently and the frequency where both peaks overlap the most will reach the laser threshold first. This will be the output frequency if the cavity mode coincides with these two overlapping reflectors. This is called the additive Vernier effect.

By increasing one reflector current, its reflection spectrum will move to higher frequencies and the overlapping peaks will occur at another frequency. A higher side-mode suppression than with the multiplicative Vernier effect [used with the

Fig. 1 Schematic drawing of an MG-Y laser diode

(S)SG-DBR laser] is obtained, because the neighbouring peaks that only overlap partly are also partly out of phase [1].

Thanks to a careful design of the gratings and a careful processing of the branches, only three independent tuning currents are necessary to control the device. The two reflector currents are changed to tune the frequency, and the phase current guarantees an overlap of the cavity mode and the reflection peaks.

State-of-the-art MG-Y lasers [11] show a wide tuning range (191.05–196.80 THz) while retaining a high side-mode suppression ratio (SMSR) (>40 dB). A high output power (>13 dBm) and a low power variation (<1.5 dB) are possible without additional amplification because the light does not have to pass a lossy reflector section before exiting the laser cavity. The fabrication of the lasers moreover is not more complex than that of an ordinary three-section DBR laser diode.

For mode stabilisation purposes, an integrated photodetector was added after each reflector in order to be able to measure the light transmitted through the Bragg grating.

3 Look-up table generation

Creating a look-up table comes down to finding reliable operating points that guarantee continuous tuning at a constant power level.

The presence of three control currents makes this calibration quite complex and time-consuming. Additionally, hysteresis occurs in all DBR-type lasers, but the hysteresis in MG-Y lasers is substantial and covers up to 50% of the cell area. This is slightly more than that of a commercially available DBR and GCSR lasers. It is expected that hysteresis will be further decreased in further optimised MG-Y designs. Owing to hysteresis, the characteristics of the measured point change depending on the previously measured point, so it is difficult to find reliable operating points.

In a first step, a coarse power plane measurement (Fig. 2) is carried out in which the power is measured as a function of the two reflector currents while the gain current is increased during tuning to compensate for the tuning losses in the reflectors. From this measurement data, reliable operating points can be extracted (e.g. using an image processing technique) where the overlap between the reflector peaks and the cavity mode is optimal, causing a high side-mode suppression and a high output power.

Secondly, the influence of the phase current is investigated by repeating the power plane measurements for different phase currents. With increasing phase current, the power plane measurements show that cells (shaped by the mode boundaries) move to higher reflector currents and that the found operating points are at higher frequencies. By only changing the phase current, tuning of approximately 100 GHz is possible before a mode jump occurs. Through interpolation, any frequency within these tuning limits can be located.

For every frequency on the ITU grid (with a 50 GHz spacing) within our tuning range, two optimal operating points are extracted for a power above and below the target power level (Fig. 3). Out of those two sets of operating points, the ultimate set at the wanted power level can be extracted through interpolation.

Fig. 2 Output power in function of reflector currents

Using the algorithm described previously 90 channels between 192.35 and 196.8 THz were extracted. Fig. 4 shows the achieved power levels and side-mode suppression levels. All channels were within ± 2 GHz in frequency of the desired ITU point and ± 0.2 dB in power of the target value. The side-mode suppression was measured to be greater than 35 dB for all channels.

4 Control and stabilisation: concept

A control scheme based on integrated photodetectors is presented, which is capable of locking the operating point to the middle of a cell. This guarantees that the laser can continue operating even when the environmental conditions change or when the tuning sections of the laser diode degrade.

Degradation and environmental changes cause a frequency drift of the output signal. This can be compensated by using a wavelength locker that changes the phase section current. However, frequency locking is only possible for a limited frequency shift because a mode hop occurs when the laser degrades too much and the frequency will then stabilise at the wrong ITU frequency. In a good control system, a frequency locker is used in combination with a mode stabilisation system.

Integrated photodiodes are used for this mode stabilisation. In our tunable laser diodes, a high side-mode suppression and high output power are obtained when the cavity mode overlaps with a reflection peak of both reflectors. At each reflection peak, the light transmitted through the reflector and detected by the integrated photodiode is then minimal. So, an optimal operating point coincides with a minimum in both detector currents.

Fig. 3 Output power of operating points in both the low power (plot at ~ 7 mW) and high power (plot at ~ 9 mW) coarse characterisations

Dashed line in between is the target power (8 mW)

Fig. 4 Frequency error, output power and side-mode suppression for final set of operating points at different ITU frequencies

The cell indicated by the dashed oval line in Fig. 2 was examined by sweeping the reflector current along a horizontal and a vertical line. Fig. 5 shows for both sweeps the measured output power and the measured detector current corresponding with the changed reflector current. The measurements in Fig. 5 show that within a cell, there is a clearly defined detector minimum to lock to.

Locking can be easily implemented because the minimum of the monitor diode can be detected by dithering the reflector currents. This way the reflector currents can be adjusted to stabilise the laser operation in the middle of the cell and prevent a mode hop.

In our feedback scheme, the light coming from the laser diode is coupled into a fibre. A small part of this light is sent through an etalon to create a frequency error signal that corrects the phase current. This way the output frequency is locked to a point on the ITU grid. At the same time, the detector currents are used to lock the mode into the middle of the cell, compensating frequency drifts and expanding the lifetime of the device.

5 Control and stabilisation: experiments

Through a series of tests, the frequency and mode stabilisation algorithms described previously were experimentally

Fig. 5 Variation of detector current and output power as the reflector current is varied vertically and horizontally through the cell, which is indicated by the white dashed oval in Fig. 2

proved. The stability of the MG-Y laser diodes is so good that it is impossible to detect the effects of ageing during operation. To reproduce the effects of degradation in the tuning sections over a longer time period, the temperature of the laser sample was slowly swept.

In a first series of tests, the laser was set up at a certain ITU frequency and the temperature was increased to check the degradation effects. Fig. 6 shows what happens to the frequency when only the mode stabilisation is used. The algorithm compensates the temperature effects so that the laser keeps lasing in the same mode over a large temperature range. This way the same position within a cell can be maintained over more than one longitudinal mode. A mode hop can be prevented, which would not be the case if we would only stabilise the frequency through the phase current.

In a second series of tests, the previously tested stabilisation scheme is used in combination with a wavelength locker while the temperature is swept from 19 to 28°C in steps of 0.5°C. At each step, the phase current decreases to maintain the target frequency. At the same time, the reflector currents are changed to maintain a constant position of the operating point within the cell. The movement of this cell is not only caused by the temperature change but also by the changes in the phase section current induced by the frequency stabilisation loop.

These feedback tests are shown in Fig. 7 for three different temperatures. The output power cells move over a considerable range as the temperature is increased. The tuning currents are decreased by the stabilisation algorithm to compensate for this temperature change. There is no mode hop though, because the cell shifts in the same direction of the operating point so that a constant position within the cell can be sustained. For each temperature, the operating point is stabilised around the highest output power within the cell.

These experiments prove that feedback mechanisms for frequency and mode stabilisation are able to endure a considerable amount of degradation in the tuning sections of the laser diode, leading to making recalibrations unnecessary. The lifetime of the device is greatly expanded.

The locking based on detector currents is much more accurate than the output power locking [6] or the voltage locking [7] where nonlinear cavity effects and tuning-induced losses deteriorate the stabilisation. Additionally, the detector currents have a much smaller range than the active voltage values, which makes it easier to obtain a higher sensitivity. So, the detector stabilisation has advantages over previously published mode stabilisation concepts.

Fig. 6 Variation of right and left reflector currents and frequency while the temperature is swept between 20° and 25°: thanks to the stabilisation scheme a mode hop is prevented

a

b

c

Fig. 7 Variation of the operating point during mode and frequency locking while the temperature is changed from (a) 19° to (b) 23° and (c) 28°. A constant position within the cell can be sustained preventing a mode hop

6 Conclusions

In this article, an algorithm for characterisation has been given, which is able to find good operating points at

standardised points over a large frequency range of more than 5 THz. All these points exhibit only a very small deviation from the target output frequency (± 2 GHz) and power (± 0.2 dB) and an SMSR of over 35 dB.

We also demonstrated a stabilisation algorithm with phase current control derived from a wavelength locker and a reflector current control derived from the photocurrent of photodetectors added to each reflector. The phase current control is used to stabilise the optical frequency. The reflector currents are adjusted to minimise the output of the photodetectors, which have been integrated monolithically with the laser diode.

This stabilisation scheme guarantees that the operating point remains at the centre of the cell, preventing a mode hop. This feedback algorithm guarantees that the laser continues operating at the wanted frequency even when the tuning sections degrade or when environmental conditions change. Thanks to the algorithm, no re-calibrations have to be carried out.

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