State-of-the-art performance of widely tunable modulated grating Y-branch lasers

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Abstract: Novel monolithic tunable laser diode with wide tuning range (191.05-196.80 THz), high side-mode suppression ratio (> 40 dB), high output power (> 13 dBm) and low power variation (< 1.5 dB) without additional amplification.

OCIS codes: (140.3600) Lasers, tunable; (140.5960) Semiconductor lasers; (060.2380) Fiber optics sources and detectors

1. Introduction

Widely tunable lasers have been in the focus of the photonics industry for many years now, since they are considered key enablers for intelligent all-optical networks that provide carriers with greater flexibility, faster provisioning, and, crucial in the current economic environment, much lower costs. A wide range of solutions have been proposed, from miniaturized external cavity lasers [1], through micro-mechanically tuned vertical cavity surface emitting lasers [2], to thermally tuned DFB arrays [3]. Only one class of tunable lasers can however be monolithically integrated with a modulator, which is required to achieve a low-cost transmitter module, and provide the fast tuning (switching time ~10 ns) required for future systems based on optical burst mode switching. These are the monolithic electronically tuned distributed Bragg reflector lasers employing modulated grating reflectors with multiple reflectivity peaks to achieve wide tuning. Examples are the sampled grating DBR (SG-DBR) laser [4] and the grating coupler with rear sampled grating reflector (GCSR) laser [5]. In this paper we present the first experimental results on a new and improved tunable laser diode in this class, the modulated grating Y-branch (MG-Y) laser (Fig. 1) [6-7].

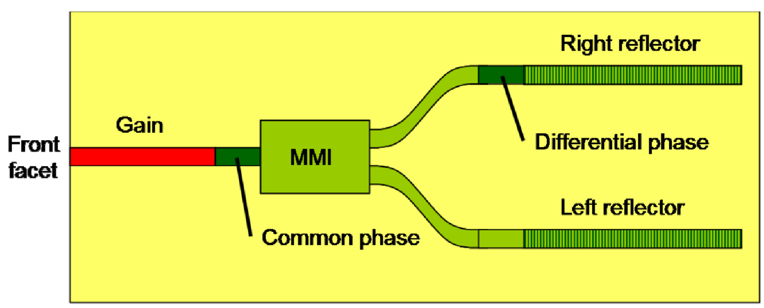

Fig. 1. Schematic lay-out of the modulated grating Y-branch (MG-Y) laser.

The MG-Y is similar to the SG-DBR in that it uses the Vernier effect to achieve wide tuning with two multi-peak reflectors. One disadvantage with the SG-DBR laser is that the output light has to pass through the front reflector, in which significant free carrier absorption occurs when current is injected. As a result, the output power of a SG-DBR laser varies significantly with tuning (> 3 dB). The MG-Y is comparable to the GCSR laser in the sense that it has all tuning sections on the same side of the gain section, such that the light can exit the cavity without absorption, enabling higher and more even output power across the tuning range. Instead of using the Vernier effect, the GCSR laser uses a widely tunable coupler transmission peak to efficiently select one reflector peak for lasing. The main disadvantage of the GCSR is that the chip is rather long, which reduces the cavity mode spacing and yields somewhat lower side-mode suppression ratio.

2. Device design and fabrication

Conceptually, one main difference between the SG-DBR laser and the MG-Y laser is that for the MG-Y the super-mode selection is performed by an addition of the complex amplitudes of the reflectivities instead of a multiplication. Since the addition is sensitive to the phase difference between the reflections, the shape of the aggregate reflection spectrum is not self-evident. At first sight, one would expect to need a differential phase control in order to match the phases of the reflections from left and right reflector. However, as described in [7], when properly designed the addition suppresses the adjacent peaks strongly although these side peaks overlap. By applying a set of design rules for the reflectors, one can ensure that the same differential phase will apply for all operation points in the main repeat mode, where reflectivity peaks of the same order are aligned, i.e. where peak n from the left reflector is aligned with peak n from the right reflector (n = -4, -3, …, +4, +5) [7]. If, on top of that, during fabrication care is taken not to introduce any significant asymmetry between the waveguides in both arms of the Y-branch, the initial differential phase will be 0 and no differential phase tuning will be required at all for operation points in the main repeat mode. The results below will show that this was successfully achieved in the first fabricated batch of MG-Y lasers.

In the current design of the MG-Y laser, the light is split by the use of a 60 μm long, 7 μm wide multi-mode interferometer (MMI). Then 115 μm long S-bends with a 255 μm radius of curvature are used to increase the separation between the waveguides. Each arm ends with a 500 μm long multi-peak reflector with an effective coupling coefficient of 30 cm^{-1}. In one arm there is an 80 μm long differential phase section that can be used to adjust the phase difference between the reflections. A common phase section of the same length is used to align the cavity mode with the reflector peaks. The device is manufactured as an InP/InGaAsP buried hetero structure laser, with a 400 μm multi-quantum-well gain section butt-joined to the passive sections made in a 0.35 μm thick InGaAsP layer with a photo-luminescence wavelength of 1.39 μm. The fabrication process is essentially the same as that of a standard DBR laser, with 5 MOVPE steps. Stitching error free gratings are fabricated in the two reflectors by electron beam lithography and wet chemical etching. In order to boost the output power, a low-reflectivity coating is applied to the front facet after cleaving, reducing the power reflectivity from 28% to a few % and thus enhancing the slope efficiency of the laser.

3. Device performance

Fig. 2 reveals a map of the output frequency as a function of the tuning currents in both reflectors for a typical device, measured at a constant gain current of 150 mA, and a common phase current of 0 mA. For a vast majority of devices from the first batch no differential phase tuning is needed to achieve in-phase addition of the reflections when reflectivity peaks of the same order from both reflectors are aligned, illustrating the robustness of the design. Consequently, the differential phase section can be eliminated in future versions, and only 4 sections need to be controlled to achieve full power and frequency control, i.e. the same number of controls as a SG-DBR or GCSR laser.

When devices are fully characterised in order to determine the reflector and phase currents required to tune the laser to the channels on the ITU-grid in the C-band, very regular patterns are obtained, as illustrated by Fig. 3. This implies that the devices have no spurious reflections at butt-joints and other interfaces. Tuning currents are low, less than 16 mA, which is important for fast switching of the lasers since this results in reduced thermal transients when changing channel. The lasers can be tuned from 191.05 THz to 196.80 THz with side-mode suppression ratios of more than 40 dB (Fig. 4). Fig. 5 shows the front facet output power at a gain current of 150 mA and a submount temperature of 25°C for the operation points in Fig. 3. The average output power is about 14 dBm, and the variation is only 1.2 dB across the depicted tuning range of 5.8 THz.

4. Conclusion

The first batch of MG-Y lasers manufactured within the EU-funded project IST-2000-2844 NEWTON sets a new standard for monolithic widely tunable laser diodes. Without additional amplification, the MG-Y lasers yield higher output power (more than 13 dB across the tuning range from 191.05 to 196.80 THz), and significantly lower output power variation (below 1.5 dB) than SG-DBR lasers. The side-mode suppression ratio is higher than that of GCSR lasers, above 40 dB for all operation points. Also, it was proven that the differential phase section can be eliminated in future versions, and only 4 sections need to be controlled to achieve full power and frequency control.

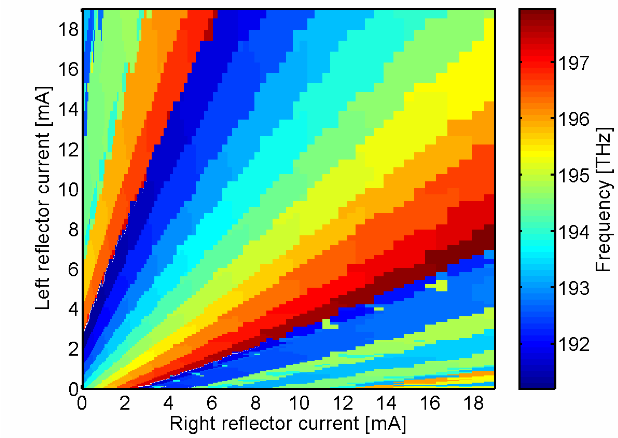

Fig. 2. Measured map of output frequency as a function of left and right reflector currents. Gain current: 150 mA, common phase current: 0 mA, differential phase current: 0 mA.

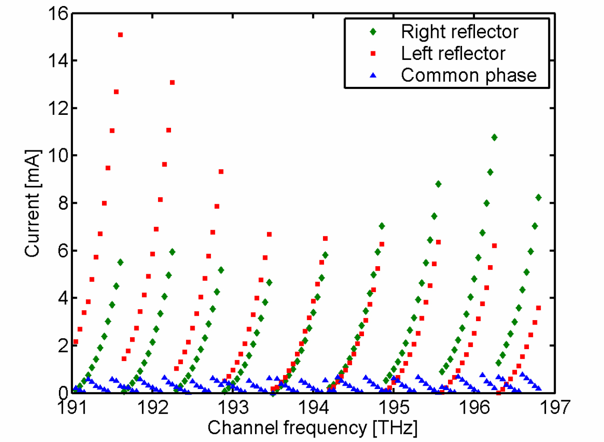

Fig. 3. Tuning currents for ITU channels from 191.05 THz to 196.80 THz. The differential phase section is not used.

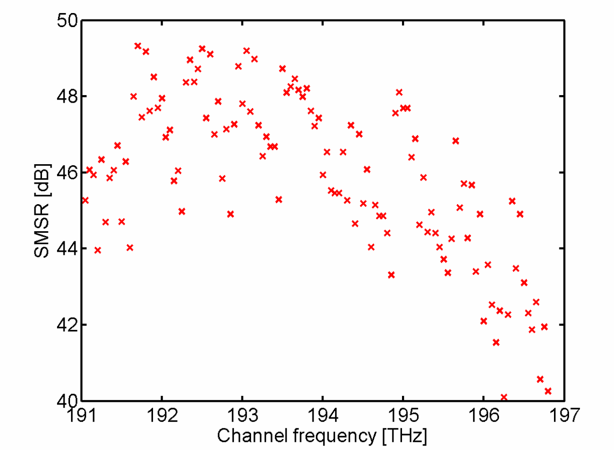

Fig. 4. Side-mode suppression ratio for ITU channels from 191.05 THz to 196.80 THz.

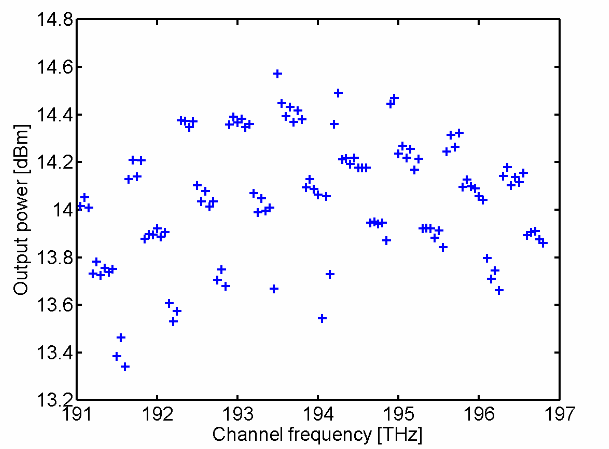

Fig. 5. Front facet output power for ITU channels from 191.05 THz to 196.80 THz at a constant gain section current of 150 mA.

5. References

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