Optics Communications 284 (2011) 1616–1621

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Characterization of a tunable three-section slotted Fabry–Perot laser for advanced modulation format optical transmission

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ARTICLE INFO

Article history:
Received 2 July 2010
Received in revised form 5 October 2010
Accepted 7 November 2010

Keywords:
Advanced modulation formats
Linewidth
Lineshape
Slotted Fabry–Perot laser

ABSTRACT

In this paper we report on the characterization of a narrow linewidth three-section tunable slotted Fabry–Perot laser. The SMSR of the 25 available 100-GHz ITU channels is above 30 dB, whereas their average linewidth is 538 kHz with a maximum below 800 kHz. The RIN spectra of six different channels are also measured and a maximum average RIN of −135 dB/Hz is obtained. The linewidth effect of the laser in a 1.25 Gb/s DPSK transmission system is investigated by comparing the performance between the slotted Fabry–Perot laser and a commercial SG-DBR laser respectively. Error free transmission of the slotted Fabry-Perot laser shows the benefit of the narrow linewidth of the device for systems employing advanced modulation formats.

1. Introduction

Dense wavelength division multiplexing (DWDM) systems have been widely deployed in optical networks to increase the capacity of a single fiber. However the demand for increased bandwidth is being driven by newly developed technologies such as voice over Internet Protocol (VoIP) and P2P networking. In order to meet the bandwidth requirement, the data rate of each channel in the DWDM system has begun to migrate from 10 Gb/s to 40 or 100 Gb/s.

Due to the limited bandwidth of erbium doped fiber amplifiers (EDFA) spectrally efficient modulation formats such as dual polarization quadrature phase shift keying (DP-QPSK) are being deployed to achieve higher aggregate data rates while remaining within the bandwidth limits set by the 50 GHz ITU grid. Because these advanced optical modulation formats are based on modulation of the phase of the optical carrier, the linewidth of the laser, which is related to the phase noise, is increasing in importance. A narrow linewidth laser enables lower baud rates and/or higher order modulation formats without relying on digital signal processing (DSP) based phase reconstruction [1].

As DWDM networks begin to evolve from static point to point links to dynamic reconfigurable networks, widely tunable lasers are becoming a key component [2]. While these devices offer many desirable properties they tend to have linewidths ranging from a few megahertz to a few tens of megahertz [3,4] which is not ideal for phase noise sensitive applications. The most common widely tunable laser is the sampled grating distributed Bragg reflector (SG-DBR) laser which offers quasi-continuous tuning over wide tuning range (>50 nm), side mode suppression ratio (SMSR) of over 40 dB [5] and nanosecond scale switching times [6].

In the last few years a new type of monolithic tunable laser fabricated by etching perturbing slots into the laser ridge has been presented and demonstrated by researchers. These lasers have a single growth fabrication process and only use standard lithography, which significantly reduces the complexity and cost of fabrication while increasing the yield. This type of laser structure, known as the slotted Fabry–Perot (SFP) laser, offers wide (discrete) tunability, high SMSR and sub nanosecond switching [7]. Like the single mode devices based on a similar structure [8], this type of tunable SFP laser is shown here to also exhibit narrow linewidth [9].

The structure and operation of one such tunable SFP laser is presented in detail in Section 2. Characterization of the laser which includes the optical spectra, relative intensity noise (RIN), SMSR and the linewidth are presented in Section 3. The linewidth advantages of the three-section SFP laser over the SG-DBR laser is shown in Section 4 by employing these two types of lasers in a low data rate differential phase-shift-keyed (DPSK) system in order to reduce the laser linewidth tolerance. The narrow linewidth of the device combined with the wide tunability and low cost fabrication shows the viability of using the three-section SFP laser in dynamic networks employing advanced modulation formats.

2. Device structure and operation

The structure of the laser is shown in Fig. 1. Two single slots were etched into the ridge waveguide to separate the 647 μm long laser into

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0030-4018/$ – see front matter
doi:10.1016/j.optcom.2010.11.022

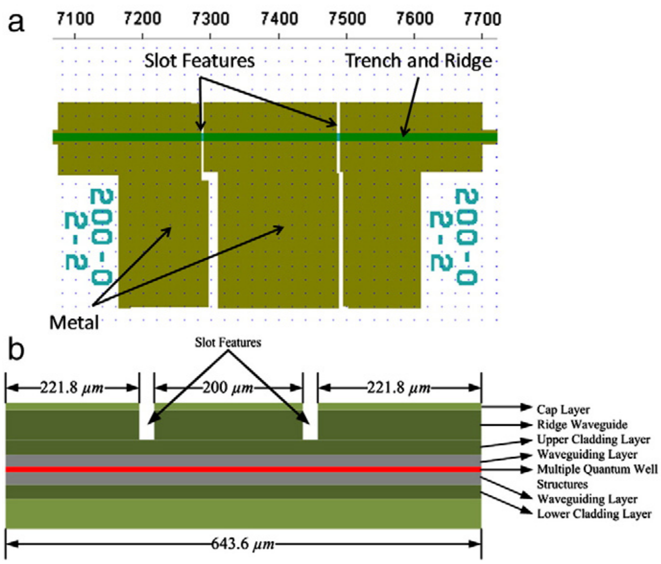

Fig. 1. (a) Mask layout of the device. (b) Longitudinal structure of the three-section SFP laser.

three independently injected active sections. The wafer material is a standard 5 QW off-the-shelf laser structure from a global wafer supplier (IQE). The slots were formed in the same etch step as the laser ridge, and did not go through the active region. However, the depth was sufficient to perturb the mode and cause a reflection at the slot position [10]. The device was mounted in a standard 14 pin butterfly package, and an 11 μm radius lens ended fiber was aligned and welded into position.

Unlike DBR-type lasers, there are no slots or perturbations within any of the sections to act as gratings. The reflections from each of the two slots that define the sections result in three mutually coupled Fabry–Perot cavities. The lasing wavelength is set by the overall gain and phase resonance conditions which can be adjusted by the current injected into each section by which the local refractive index and gain is altered. The primary mode spacing is set by the overall length of the device (647 μm) with every third mode being preferentially selected due to the sectioning of the overall cavity. This corresponds to a mode spacing of approximately 200 GHz. Smaller mode spacing can be achieved by increasing the length of each section and vice versa.

For the packaged device, it is found that the mode spacing of the middle (200 μm) and the back (211 μm) sections is larger than that of the front section (236 μm), which can be attributed to the displacement of the cleave at the back facet over the intended position. Due to the Vernier effect only a single mode from the sets of cavity modes can be aligned. Unintended variations in the actual length of the sections results in a shift in the mode map with current into the individual sections. This mode map is also dependent on the refractive indices of the individual sections which in turn are temperature dependent.

Fig. 2 shows the P–I curves of different bias combinations. The two sections (back and middle sections) with similar length were driven with the same conditions. From the figure we can see that the required current on the front section for threshold decreases with the increase of the bias on middle and back section, which means that the weakly clamped threshold carrier density of the front section is decreased according to the increasing bias on the other two sections. The same phenomenon can also be observed for the total threshold current of the middle and back section with different bias on the front section. According to the free carrier plasma effect, the refractive index is inversely proportional to the carrier density. Therefore by varying the drive current to each section (0 to 60 mA), the gain and index of each section of the laser can be controlled The aligned lasing mode can be set to hop to another one by independently varying the current on the three sections. This can be seen from the kinks on the P–I curves in Fig. 2. The figure also shows the slope efficiency of each P–I curve. The two curves exhibit relatively low efficiency (see the two dash lines) due to the fact that the total additional current is doubled as the middle and the back section was driven by the same amount of current simultaneously.

Mode hops can also be generated by temperature variations. Therefore the laser chip is packaged with an integrated thermoelectric cooler (TEC). Fig. 3 shows the temperature sensitivity of the device with two different modes. From the figure we can see that single mode lasing (SMSR ≥ 30 dB) can be maintained within a range of 7 °C. The temperature dependence of wavelength is approximately 0.11 nm/°C for both modes. However multi-mode lasing can be observed when the temperature of the device exceeds 26 °C.

3. Device characterization

The characterization setup is shown in Fig. 4. The delayed self-heterodyne method [11] is used to measure the linewidth of the SFP laser which was optically isolated to prevent optical feedback into the cavity. The delay of a 12 km single mode fiber (SMF) is approximately 60 μs, which corresponds to a resolution of 17 kHz for the linewidth measurement. Light propagating in the short arm of the setup was modulated using a $LiNbO_3$ phase modulator to frequency shift the detected heterodyne beat signal to 2 GHz thereby enhancing the measurement accuracy. The laser linewidth was then deduced from the beat frequency spectrum, measured by an Electrical Spectrum

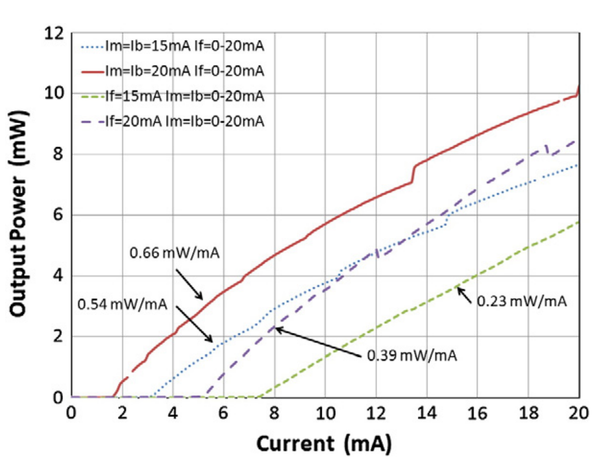

Fig. 2. Power versus current characteristic under different bias combinations. If, Im and Ib represent the current on the front, middle and back section respectively.

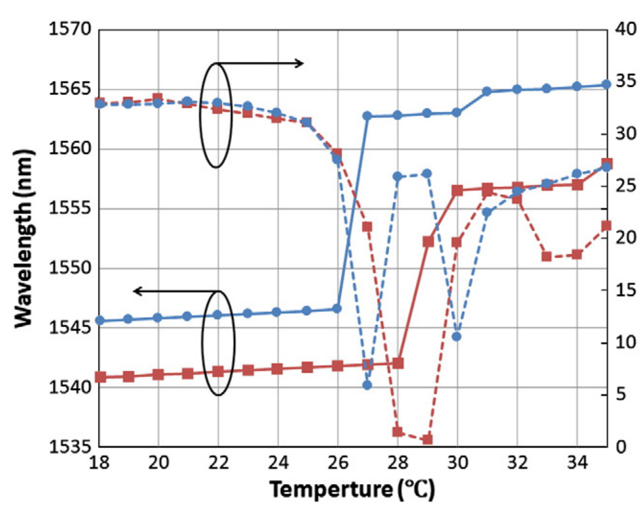

Fig. 3. Temperature sensitivity of two different modes (■ and ●). The solid lines represent the lasing wavelength while the dotted lines represent the corresponding SMSR.