40 Gbit/s Directly Modulated Passive Feedback Laser with Complex-Coupled DFB Section

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Abstract *40 Gbit/s open eyes are demonstrated for a passive feedback laser transmitter with complex coupled DFB section. The transmitter shows superior single mode emission in combination with chirp tuning capability and high reliability.*

Introduction

High bit rate, up to 40 Gbit/s, directly modulated semiconductor lasers are of crucial interest for a new generation of low-cost transmitters in short-reach and very short-reach optical links. The transmission capability of standard single section DFB directly modulated lasers is determined by the carrier photon (CP) dynamic which does not allow to achieve optical modulation bandwidths of more than 20 GHz. To overcome the CP modulation bandwidth limitation different approaches have been developed. They include the optimization of single section devices regarding gain material and device geometry, the injection locking technique, and the application of the multisection laser concept /1 and references therein/.

Within the multisection laser concepts, the passive feedback laser (PLF, Fig. 1) design has been investigated theoretically and experimentally /1,2/. The approach exploits the photon-photon (PP) resonance that exceeds the usual carrier-photon resonance frequencies a few times. Via modulation bandwidth enhancement to about 30 GHz, stable error free eye patterns for 40 Gbit/s NRZ data streams have been reported /2/.

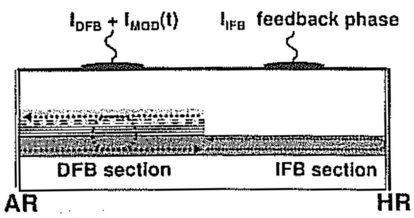

Fig. 1: Scheme of a PFL, consisting of an antireflection-coated DFB and a high-reflection coated integrated feedback section.

The PP resonance needs the interaction of DFB and cavity modes. The selection of the interacting modes is based on a weak stop band mode preselection of the individual index-coupled DFB sections. Feedback phase effects due to constructive or deconstructive interaction between competing DFB modes and cavity modes can lead to unintentional DFB mode hopping. To improve the single mode stability, devices with complex-coupled (cc) gratings in the DFB section have been realized and investigated for the first time in this paper.

In this paper we demonstrate the superior mode stability in the cc PFL devices while keeping the enhanced modulation bandwidth. First, the incorporation of cc DFB section is described. Then, their successful application in an up to 40 Gbit/s directly modulated PFL device is demonstrated. Chirp and reliability studies prove the performance of these devices as transmitter for optical data systems.

PFL device with a complex-coupled DFB section

The laser applied within the multi-section laser device is based on a ridge waveguide design. The device and its fabrication process have already been described in 1 and 2. In this work, a cc DFB grating is introduced. The rectangular grating was etched partially into the MQW by reactive ion etching (RIE). The RIE process parameters were chosen to prevent creation of etching defects.

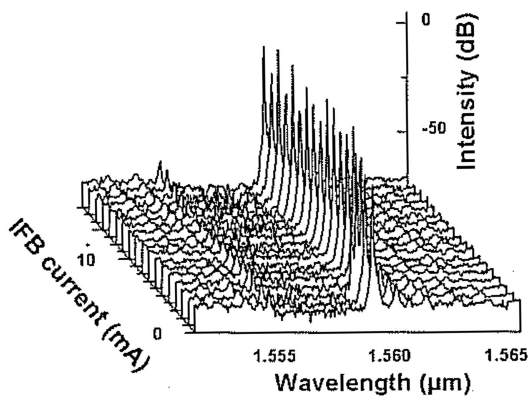

Fig. 2: Optical spectra under variation of feedback phase current (IFB current), the PFL device consists of a 230 µm cc DFB and a 250 µm IFB section.

Fig. 2 shows the spectral dependence of a cc PFL on phase current variation. The drawn IFB current range provides an approximately 2Π feedback phase rotation. According to the chosen design of an in-phase index- and gain-grating, the dominating mode is at the longer wavelength side of the stop-band. Excluding the phase current region, where self pulsation occurs (phase current around 2 mA), the side mode suppression ratio (SMSR) is better than 40 dB even under feedback conditions. No mode jumps were observed over the whole feedback phase range. Threshold is about 12 mA at

20 °C. This low threshold value indicates our gentle RIE grating formation process and good crystalline overgrowth.

Small signal and large signal analysis

When recording the optical small signal modulation response under different feedback phase conditions, varied by different IFB biasing, a strong change of the modulation bandwidth is observed. Under optimum feedback conditions, the achieved bandwidth enhancement reaches nearly 30 GHz (Fig. 3). Eye pattern measurements under these optimum feedback conditions have been carried out with 2^7-1 pseudo random bit sequence (PRBS) data streams for Non-Return-to Zero (NRZ) 40 Gbit/s signals. A clearly open eye have been recorded with an extinction ratio of 6 dB (see insert of Fig. 3). Note that these measurements have been performed with an HF probe on laser chip level with sub optimum impedance matching, resulting in multiple traces.

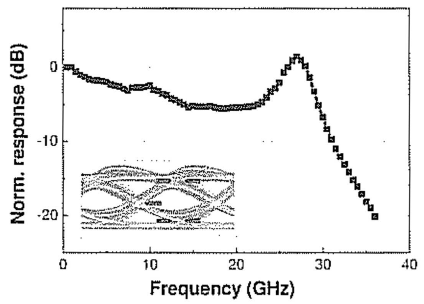

Fig. 3 Small signal modulation bandwidth and back to back eye pattern of a PFL structure under optimum feedback phase condition and a cw DFB current of 80 mA.

Chirp

For the chirp studies, a cc PFL with a high linewidth enhancement factor was chosen. Fig. 4 shows that the adiabatic chirp behaviour can be managed by variation of the feedback phase. Left side of Fig. 4 illustrates the spectrum under 1 Gbit/s modulation. The derived chirp (line splitting) and intensity difference in dependence on phase current is shown in the right part of Fig. 4.

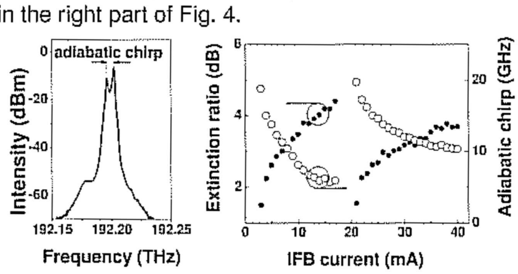

Fig. 4: Adiabatic chirp of a cc PFL device under digital modulation at 1 Gbit/s. Left: spectrum and right: chirp and extinction dependence on phase current.

The lowest chirp value of 5 GHz has been achieved at a cc PFL operation point where the extinction ratio has its maximum (operation point for 40 Gbit/s data rates). If the data rate potential of the cc PFL is not fully required (i.e. moderate bit rates up to 25 Gbit/s), the transmitter gives the additional degree of freedom to manage the chirp via phase current variation.

Reliability

Fig. 5 shows the results of a 2400 hour high temperature life test study of four integrated feedback cc PFL devices conducted in a constant current mode (80 mA) at 85 °C. The laser threshold is measured periodically at 20 °C and 50 °C. The threshold dependence shows only marginal degradation within the error limit of our reliability test setup. The normalized cc PFL output power shows degradation in the order of $2x10^{-5}$ /h. If we define end of life as a 20 % change in output power and extrapolate to the aging behaviour at room temperature, life time can be estimated to about 100000 h.

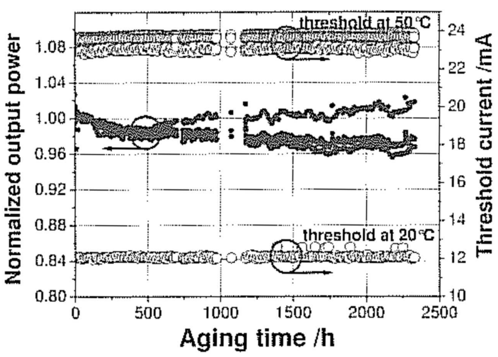

Fig. 5: Aging data for threshold and output power for cc PFL devices operated at 85 °C and 80 am.

Summary

For a multisection PFL transmitter including a complex-coupled DFB section optical modulation bandwidth of 30 GHz and open eyes for large signal 40 Gbit/s direct current modulation with 6 dB extinction ratio have been demonstrated. The device shows high single mode stability under varying phase conditions of the integrated feedback which is necessary for optical bandwidth enhancement. For data rates below 40 Gbit/s, the PFL structure has the potential to be applied for feedback controlled chirp management, thus opening up a huge potential for applications in new highly dispersion tolerant modulation formats. Reasonable life times of about 100000 h could be estimated proving reliable technological fabrication.

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References

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