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Direct modulation and down scaling of light sources in generic foundry COBRA

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We present an experimental study into the use of simple Fabry Perot lasers for integration in generic platforms. Such integrated FP lasers offer the advantage of freedom of placement anywhere on the chip and, easy integration with monitoring and control functions. They can play a role in short range data communications and they have a potential for 10 Gb/s direct modulation speed. We report first results on experimental realization of such lasers including eye diagrams and BER testing results.

Introduction

Colourless Wavelength Division Multiplexed Passive Optical Networks (WDM-PON) have recently gained importance for short reach optical access. The advantages of colourless transponders are cost reduction in deployment, operation and maintenance as the same equipment can be used for variable wavelengths. Fiber amplifiers and external modulators, which are widely used in long-haul applications because of their high performance in data rate and transmission reach, are considered too expensive for end user access networks, where low-cost and high-volume deployment is of paramount importance [1]. Therefore, a passive network structure with direct modulation schemes is preferred. Currently, several formats are used for WDM-PON networks, such as externally seeded or self-seeded schemes or arrangements based on tuneable lasers. Among those, the externally seeded WDM-PON technology has been first adopted commercially [2]. Yet, this approach is expensive because arrays of external lasers are needed at the central office (CO) location and a more cost-effective solution like the self-seeded architecture is preferred in future WDM-PONs. Self-seeded Reflective Semiconductor Optical Amplifiers (RSOAs) and Fabry-Perot Laser Diodes (FP-LDs) have been proposed for that purpose due to their low cost and low complexity [3]. In addition to eliminating the need for an external seeding light, the utilization of FP-LDs can avoid crosstalk generated by Rayleigh backscattering [1]. Further cost and size reduction and lower power consumption can be achieved when FP-LDs are fabricated with photonic integration technology [2], which will be the focus in this work.

We present the design, the laser dynamics and the characterization of short FP laser cavities fabricated in the COBRA generic integration platform. Emphasis is put on short FP cavities in order to achieve increased integration density and further cost reduction. Additional optimizations can adapt these devices to fulfil the needs for future WDM-PON networks.

Fabry-Perot cavity design and dynamic simulations

Realization of short FP directly modulated lasers in standard photonic foundry platforms is important and opens up the opportunity to scale-out the number of lasers per standard multi-project wafer cell, resulting in further miniaturization and cost reduction. Here, FP lasers of variable cavity lengths have been designed and fabricated in MPW runs offered by the SMART photonics foundry. The shortest lasing devices have lengths of 250 µm and 350 µm. The lasers are fabricated on III-V substrate material, containing InGaAsP quantum wells (QWs) with 65 cm^{-1} gain at 7 $\mathrm{kA/cm}^2$ injection with a bandwidth of 195 nm. The cavity mirrors are realized through one- and two-port multi-mode interference reflectors (MIR) with 60% and 45% reflectivity and the Free Spectral Range (FSR) of the two FP cavities are 1.3 nm and 0.92 nm, corresponding to 150 and 212 spectral lines for the short and long cavities respectively. The laser output is connected to an angled waveguide, routed to the chip's facet, which is used for coupling to single mode fiber (SMF). One of the key parameters of directly modulated lasers is the modulation speed and achievable transmission bit rate. In Fig. 1, the small signal frequency response of both lasers with different cavity lengths is presented for two current injection values above threshold. In case of NRZ-OOK modulation, the maximum achievable large-signal bit rate is given by 1.3B, where B is the small signal bandwidth [4]. This relation has been obtained from the analysis of large signal switching transients in high speed III-V lasers with quaternary active region, where the turn-on and turn-off delays and transition times can be estimated from its small signal resonance frequency [4]. The small signal frequency response has been calculated here using the transfer function expression

$$H(\omega) = \frac{{\omega_R}^2}{{\omega_R}^2 - \omega^2 + j\omega\gamma}$$

where, ω_R is the relaxation oscillation frequency and γ is the damping factor.

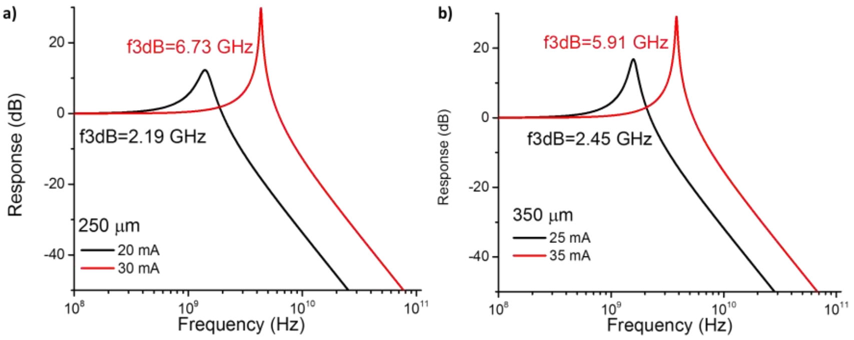

Figure 1. Small signal analysis for directly modulated FP lasers of 250 µm and 350 µm length.

Note that the curves in Fig. 1 do not take into account the effect of gain compression, which strongly dampens the relaxation oscillation behaviour and might lead to a decrease of modulation bandwidth. The calculation results indicate that under injection currents above 30 mA the 250 µm long laser has a modulation bandwidth exceeding 6.7 GHz whereas the 350 µm long laser exhibits still 5.9 GHz of bandwidth. This suggests that bitrates up to 8.7 Gb/s and 7.7 Gb/s are possible for the short and long FP lasers under direct modulation. We foresee that further optimizations can lead to an increase in modulation speed, making these lasers suitable for next generation 10 GPON networks as suggested in [2].

Experimental Measurement

To characterize the fabricated devices the setup shown in Fig. 2 is used. A bit pattern generator creates a Pseudo Random Bit Sequence (PRBS) of 2^{11}-1 length, which is used for direct modulation of the 350 µm and 250 µm long lasers at 4 Gb/s and 5 Gb/s respectively. A DC current is used to bias the lasers around the lasing threshold. Both the PRBS and the DC signal are combined with a bias-tee and fed to the laser through GSG RF probes. The laser output is collected through a lensed SMF by accurately aligning it to the angled output waveguide. From the fiber, the signal is fed to either a detector or optical spectrum analyser (OSA) for signal control. After achieving stable lasing, the signal is amplified in an EDFA and a filter is used to suppress additional ASE noise. Afterwards, a variable optical attenuator (VOA) is used to control the input power level for BER analysis and a high-speed sampling oscilloscope is used for eye-diagram measurements.

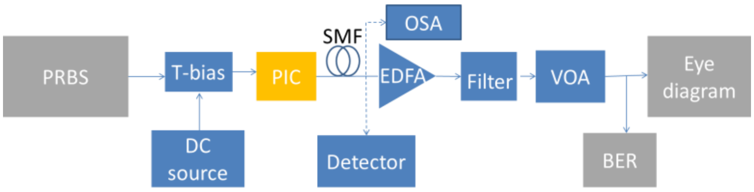

Figure 2. Block diagram of the measurement setup.

We measured five different sample chips containing several 250 µm and 350 µm long lasers and found negligible differences during the characterization. The graphs shown here represent typical characteristics of the lasers. Important graphs obtained from the measurements are L-I, V-I curves of the lasers, BER measurements and eye diagrams of the 350 µm long laser. Fig. 3 shows the measured and simulated L-I and V-I curves. The numerically simulated results were obtained from a rate-equation analysis for in-plane lasers and agree well with the measurement data.

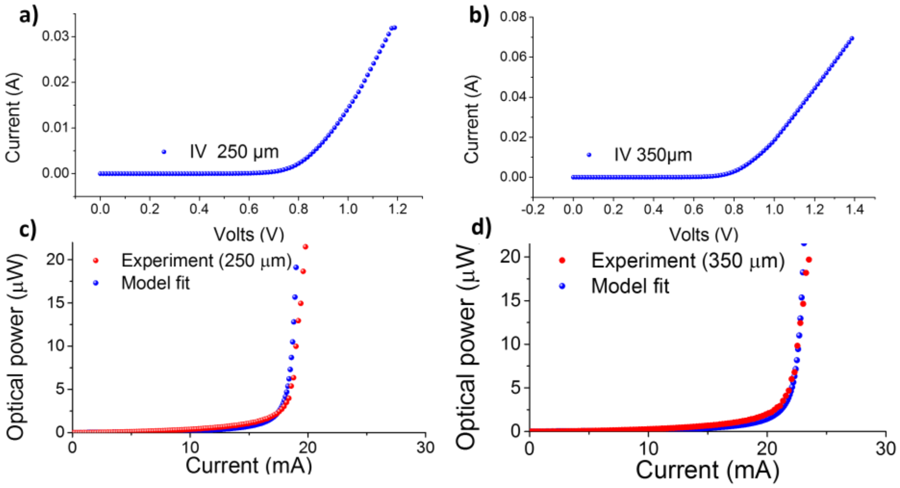

Figure 3. L-I, V-I curves of 250 µm and 350 µm FP laser cavities.

From the slope of the L-I curves in Fig. 3, the laser external quantum efficiency can be extracted, which takes a value of 8% in this case under the assumption of an optical confinement factor of 20% that has been obtained from simulations. It can be seen that the output power of these type of lasers still needs to be improved. Both cavity lengths were tested for modulation at 4 Gb/s and 5 Gb/s. However, BER measurements were only successful for the longer cavity laser since the 250 µm long laser had a fairly closed eye, preventing error free back-to-back transmission. Fig. 4 shows the BER and eye diagram for the 350 µm long cavity, modulated at 4 and 5 Gb/s with PRBS (2^{11}-1) at

43.1 mA bias current. BER of 10^{-6} was obtained until -6 dBm sensitivity and the HD-FEC error threshold of $3.8x10^{-3}$ is still met at a sensitivity of -14 dBm. The measured eye diagrams show that the modulation speed limit is around 5 Gb/s where the beginning of eye closure can be observed. At 4 Gb/s open eye diagrams are achieved. The results indicate that the short cavity FP laser is feasible of up to 4 Gb/s direct modulation and can be used as a cheap and scalable solution for WDM-PON.

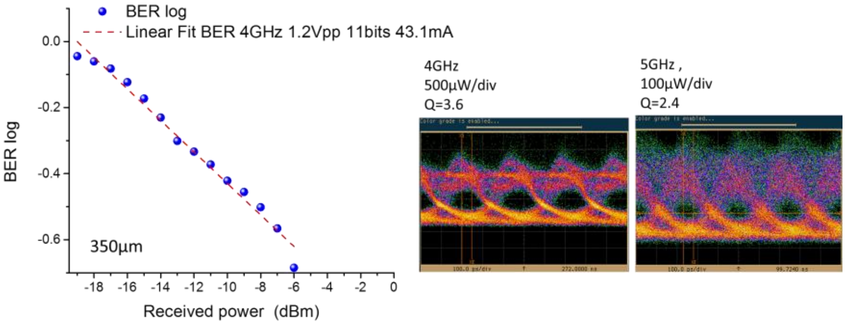

Figure 4. BER at 4 Gb/s and eye diagrams at 4 Gb/s and 5 Gb/s for a 350µm long cavity.

Conclusions

In this work the design, modelling and characterization of short FP cavity lasers on the COBRA generic PIC platform was reported. Smallest cavities that achieve lasing with this particular configuration are of 250 µm length. To further decrease the cavity length and still achieve lasing the mirror efficiency has to be improved. One option are deeply etched gratings to control emission wavelength and increase reflectivity. Cavities of 250 µm and 350 µm length were analysed in the optical and electrical domain and modelling of the small signal response for the lasers were presented. From the simulation results and using the rule of thumb proposed by [2] a direct modulation limit of ~5 GHz for the 250 µm long cavity and ~4 GHz for the 350 µm long cavity can be expected with bit rates up to ~8 and ~7 Gb/s respectively.

BER and eye diagram measurements of the 350 µm long cavity showed that 4 Gb/s is the current modulation speed limit. The modulation eye is fairly open at 4 Gb/s and BER below HD-FEC threshold can be achieved up to -14 dBm of receiver sensitivity. These type of FP lasers have the advantage of being very simple in design and fabrication as well as small in size, which transfers into low fabrication costs and the capability of high volume production. Single mode emission and moderate tunability is possible by changing temperature and bias current or potentially using injection locking mechanisms. Further optimization of the laser’s series resistance and reduction in its size can lead to higher modulation speeds, making them good candidates for next generation WDM-PON networks.

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