De-multiplexing coherent optical combs within Photonic Integrated Circuits

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Significant research effort has been directed towards successfully demultiplexing the coherent optical combs for use in Coherent Wavelength Division Multiplexing (CoWDM) technologies. Photonic Integrated Circuits (PICs) are a low cost and energy efficient solution. The selective amplification attainable of a target optical comb line via injection locking has already been demonstrated [1]. Here, we investigate the effect device gain has on the amplification of the target and neighbouring comb lines, in an attempt to maximize the side mode suppression ratio (SMSR) achievable using a MMI and slotted Fabry-Perot device. The schematic of the setup consisting of Tunable laser source (TLS), Mach-Zehender Modulator (MZM), Polarization controller (PC), Erbium doped fibre amplifier (EDFA), Photonic integrated circuit (PIC), and the optical spectrum analyzer (OSA) as well as the device under test are presented in Fig. 1. The slave SFP laser was biased to slightly above threshold where it was operating as a multimode laser diode. MMI is biased so that it is transparent and not absorbing the light.

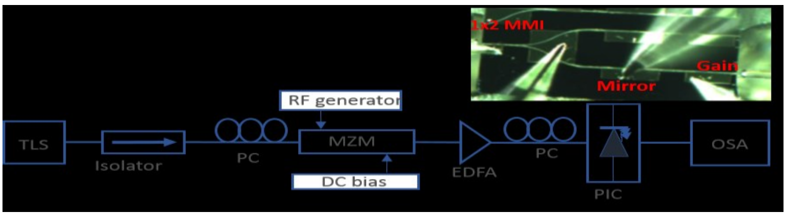

Fig 1: Schematic of the test setup. The inset shows the actual picture of the device which consists of 1x2 MMI, and 2 laser arms.

Initially the wavelength was swept across the resonance of the slave laser. The signal was generated by modulating single wavelength output from TLS. RF frequency was set to 12.5 GHz, and MZM was biased at the null so that the main carrier was suppressed and a 2 line coherent optical comb was generated. This created 12.5 GHz sidebands on each side of the carrier (see Fig. 2a), and would make observations relatively easier on the OSA when the injection locking happened. This is an ongoing experiment and the following step is investigating the de-multiplexing behavior of a comb with 3 lines of equal power. Traces of the OSA recorded for each injected wavelength were used to generate a two dimensional plot which can be seen in Fig. 2b. In this case the three injection locking regions are observed at injection wavelengths of 1551.65, 1551.7, and 1551.85 nm. Interestingly the suppressed mode was able to injection lock as well although with the SMSR less than 15 dB. An SMSR greater that 25 dB was maintained between either of the side bands while the other comb line was injection locked. Also, an SMSR greater than 20 dB is observed for the slave laser side modes.

In another experiment, the effect of driving current in the gain section was examined in order to optimize the SMSR of the slave laser as well as the gain for the filtered subcarriers in the comb. The gain current was increased from 55 to 80 mA, resulting in a higher SMSR and better filtering of each subcarriers of the comb (> 20 dB). However, increasing the current made it more difficult to injection lock the slave laser at some point: e.g. at 80 mA drive current injection locking did not happen. Due to page restrictions, the data is not presented.

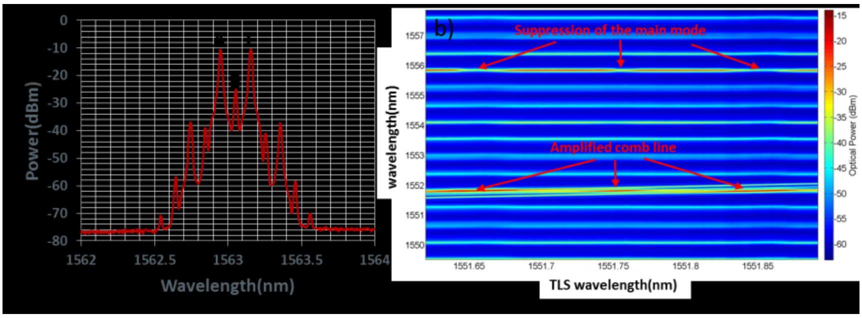

Fig 2: a) Example of the comb signal used for injection. B is the carrier, and A, and C are side bands generated with 25 GHz spacing. b) Intensity plot presenting the optical spectrum of the slave laser as the comb is injected. Each of the subcarriers are injection locked to a laser side mode. Here the laser main mode is suppressed with SMSR bigger that 20 dB. The gain for any of the filtered subcarriers is in excess of 25 dB.

A rate equation model is used to model the comb frequency suppression as the internal gain of the PIC was varied. The model assumes the MMI introduces coupling losses and a phase change to the frequency comb, and the slotted Fabry-Perot device is assumed to be single mode. From Ref. [1], the field within the device is assumed to vary as:

$$\frac{d}{dt}E_s(t) = \frac{1}{2}\left[2i\omega(N) + G(N) - \frac{1}{\tau_p}\right]E_s(t) + \frac{K}{\tau_{in}}E_c(t) \quad (1)$$

where E_s and E_c are the slave and comb electric fields, ω and G are the optical frequency and differential gain of the slotted Fabry-Perot device, and are dependent on N , the carrier density in the gain section of the device. G_N is assumed to be constant across the frequencies in the model. τ_p and τ_{in} define the photon lifetime and round trip time within the device, and K includes the coupling losses and phase change due to the MMI. As in [4], the rate equations are modified from Ref. [2,3] to include the multiple comb frequencies, by assuming that $E_c(t) = \sum_j E_{inj} e^{i(w_j t + \psi)}$, where ω_j are the frequencies of the comb lines. The rate equations are then modelled as:

$$\frac{d}{dt}E_s(t) = \frac{1}{2}G_N(N(t) - N_{th})E_s(t) + E_{inj}\sum_j \cos\left(\delta\omega_j t - \phi_s(t)\right) \quad (2)$$

$$\frac{d}{dt}\phi_s(t) = \frac{1}{2}\alpha_H G_N[N(t) - N_{th}] + \frac{E_{inj}}{E_s(t)}\sum_j \sin\left(\delta\omega_j t - \phi_s(t)\right) \quad (3)$$

$$\frac{d}{dt}N(t) = R_p - \frac{N(t)}{\tau_s} - G_N[N(t) - N_{th}]E_s(t)^2 - \frac{1}{\tau_p}E_s(t)^2 \quad (4)$$

where $\delta\omega_j$ is the detuning between each comb line and the slotted Fabry-Perot laser's frequency. The numerical simulations will be compared with the experimental results, as the gain of the slave laser is adjusted.

References

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