Nonlinear effects of four wave mixing in InP optical circuits at 1550 nm

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***Abstract*-We demonstrate how side bands arising from four-wave-mixing in semiconductor optical amplifiers affect the generation of nonlinear dynamics in photonic integrated circuits.**

Keywords-component; four-wave-mixing, nonlinear dynamics, photonic integreated circuits, mutual coupling.

I. Introduction

As demand for transmission capacity continues to grow, closely spaced multicarrier systems combined with advanced modulation and coding techniques offer routes to more fully exploit the available bandwidth of optical fibre. Such systems require integration of key optical components into a single photonic integrated circuit (PIC) [1]. However as system requirements drive PIC complexity higher there arise many more possible mechanisms for mutual coupling between active circuit elements. Moreover semiconductor optical amplifiers (SOAs) are increasingly required in PICs to compensate for optical losses. These SOAs exhibit non-linear behaviour such as four wave mixing (FWM) [2] which has a significant impact on the performance of multicarrier systems. We have shown previously how mutual coupling in a PIC produces nonlinear dynamics (NLD), depending upon the coupling magnitude and the frequency detuning [3,4,5]. In this paper we extend this work to examine the effects on PIC dynamics arising from FWM in on-chip SOAs.

II. Optical chip with FWM control

A. Physical Chip and Parameters

Figure 1 shows a diagram of the InP-based PIC studied here. It consists of 2 tuneable (~8 nm) DBR lasers whose fundamental lasing wavelengths are 1561 nm and 1555 nm, the outputs of which are coupled into an SOA via a multimode interference coupler. An aligned fibre acts to collect the chip output, and also provides reflection thereby giving a mutual coupling mechanism between the lasers [3,4,5]. The magnitude of the coupling is controlled both by the SOA gain and the fibre displacement. As the FWM level is dependent only on SOA gain, there is overall control of both the FWM and coupling magnitude. The detuning parameter is controlled via the DBR tuning currents. We characterize the FWM magnitude by the 1st side mode levels (SML), which we have observed as -14 dB to -26 dB for SOA currents between 15 mA and 60 mA.

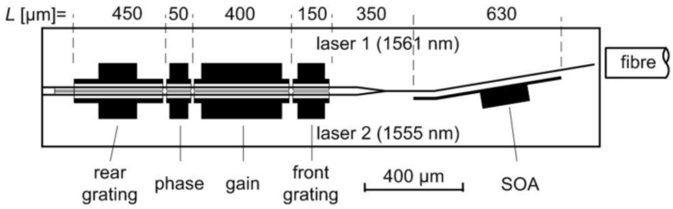

Figure 1: Schematic of the optical chip

B. Travelling Wave Model of Chip

We utilise a travelling wave (TW) model to provide a complete description of the temporal-spatial behaviour of the system [4,5,6]. The model provides for independent control of the FWM and mutual coupling through the SOA current and field transmission magnitudes. The detuning is controlled by adjustment of the phase and group indices of the DBR sections. Our current model provides SMLs of between -39 and -11 dB for SOA currents of between 20 and 160 mA.

III. Determining the conribution of FWM to NLD

A. Modelled Relations

To isolate the influence of FWM on chip dynamics we varied the FWM levels and frequency detuning, whilst keeping the total power coupling magnitude constant at -27+/-0.07 dB. For each FWM level, one of the lasers was tuned through the other in 41 detuning steps between approximately -5 GHz and 22 GHz. A transition to NLD was observed at small frequency detunings [3,4,5]. Our results show that the SOA FWM levels have a significant effect on both the frequency boundary of the dynamic transition, and on the general degree of nonlinearity. In figure 2 we show examples of the modelled optical maps for SOA currents of 40 mA (-26 dB SML) and 160 mA (-11 dB SML). The maps are plotted as the detuning between the DBR lasers versus the resulting optical spectrum. It is seen that broadband spectra characteristic of NLD are both prevalent over a greater detuning range and are much broader in the higher SML map. The detuning range of the NLD can be

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quantified as a boundary in GHz, and we have done this using 2 different methods, viz. the correlation dimension of the time series [4,5,7] and the repeatability of the time series. The repeatability is calculated as the minimum difference between a signal portion, compared with every other portion of the signal. Figure 3a shows these results, with the boundary clearly increasing with the increasing SML. Additionally, the absolute degree of nonlinearity was found by calculating the mean correlation dimension for all signals of less than 5 GHz detuning. Again this clearly quantifies an increasing degree of nonlinearity as the SML increase (figure 3b).

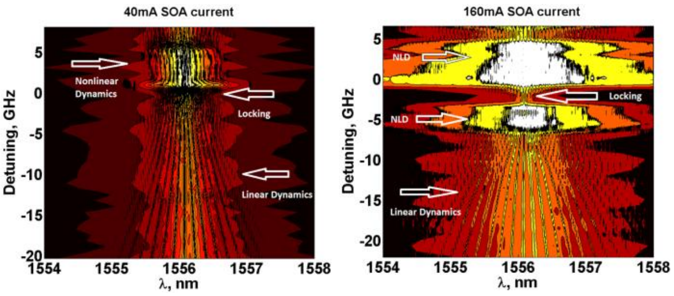

Figure 2: Optical maps for SMLs of -26 dB (lhs) and -11 dB (rhs).

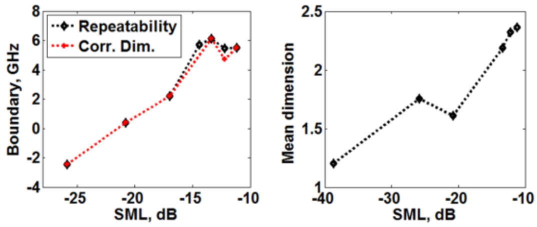

Figure 3: Modelled nonlinear trends as a function of FWM levels: 3a (lhs): frequency boundary linear-nonlinear behavior; 3b (rhs): overall degree of nonlinearity at low detuning (-5 GHz to +5 GHz).

B. *Experimental Results*

Experimental measurements were made to compare with the modelled data. A constant coupling level was achieved by increasing the SOA current and also displacing the fibre away from the chip, which reduces the degree of coupling between the reflected field and the field at the chip facet. SOA currents of 15 mA, 30 mA and 45 mA were matched with fibre displacements of 390 µm, 320 µm and 200 µm respectively. We calculated that this produced a constant coupling level of -10 dB, and a resultant coupling of approximately -26dB including -14dB fibre reflection and -2dB losses. It was found that the boundary to NLD increases strongly with SML, being 5.4, 7.4 and 8.6 GHz for SML of -26, -19 and -16 dB respectively for the 3 SOA currents. For these, we used the same correlation dimension method as for the simulated results. Figure 4 shows the single-sided spectra as the lasers are tuned across each other at 15 mA (-26 dB) and 45 mA (-16 dB) respectivly.

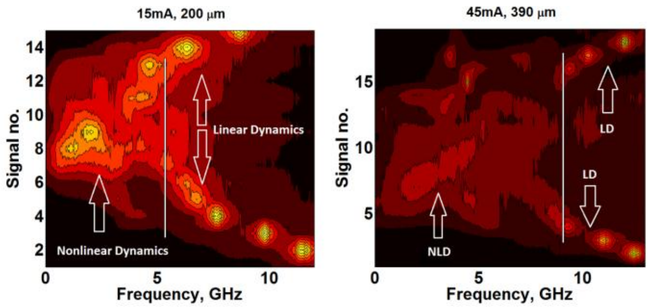

Figure 4: Experimental single-sided spectral maps for SMLs of -26 dB (lhs) and -16 dB (rhs). The vertical white lines show the boundaries between linear dynamics (LD) and NLD that were calculated using the correlation dimension of the time series.

IV. CONCLUSION

We have shown that four wave mixing levels in an SOA in a multi-active component optical system have a significant effect on the boundary to nonlinear dynamics, and the degree of nonlinearity. The increased chances of nonlinear destabilisation of the circuit must therefore be considered when including SOAs to increase PIC power levels. The current analysis uses only coupled CW signals, but will we also show the effect of FWM on coupled modulated (data) signals in such active optical circuits.

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