Investigation of an Integrated Photonic Dual-Pumped Phase-Sensitive Amplifier based on a Highly Saturated Semiconductor Optical Amplifier

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Abstract: An integrated photonic phase-sensitive amplifier with a dual-pumped four-wave mixing architecture is investigated. Gain curves with multiple periods are theoretically studied and experimentally demonstrated with approximately 7.8 dB extinction gain.

OCIS codes: (190.4380) Nonlinear optics, four-wave mixing; (190.4410) Nonlinear optics, parametric processes; (250.5300) Photonic integrated circuits; (250.5980) Semiconductor optical amplifiers

1. Introduction

During the last few years, optical phase-sensitive amplifiers (PSAs) have been attracting great research attention [1] due to the unique advantage of enabling noiseless amplification. Unlike conventional phase-insensitive amplifiers (PIAs), such as erbium-doped fiber amplifiers (EDFAs) featuring 3-dB quantum-limited NF, PSAs' noise-free amplification could significantly improve the performance of optical links and provide a wide range of applications, such as optical telecommunication, remote sensing, and optical spectroscopy and imaging, where performance of the signal to noise ratio (SNR) is critical. Various PSAs using parametric down-conversion [2] or four-wave mixing (FWM) [3] have been demonstrated; however, in most demonstrated PSAs so far, their implementations are based on bulky bench-top systems, which make it difficult to use them in practical scenarios. In [4], we proposed and experimentally demonstrated the first integrated photonic PSA chip based on a highly saturated nonlinear semiconductor optical amplifier (SOA), exhibiting the potential that a chip-scale PSA could great benefit the implementation of PSAs for practical applications.

In this paper, we further investigate the performance of the PSA chip. A theoretical model is presented to estimate the gain performance of the PSA chip and two-period gain curves with approximately 7.8 dB extinction gain are measured which agree well with the simulation results.

2. Principle and chip fabrication

Figure 1 shows a microscope picture of the fabricated PSA chip after being wire-bonded. The coherent input light waves, which are coupled into the chip, consist of one signal to be phase-sensitive amplified in a nonlinear SOA, and two pumps to be amplified by two sampled grating distributed Bragg reflector (SG-DBR) lasers thanks to injection locking, and. An on-chip phase tuner is used to change the phase of the signal for observing the relationship between the PSA gain the signal phase.

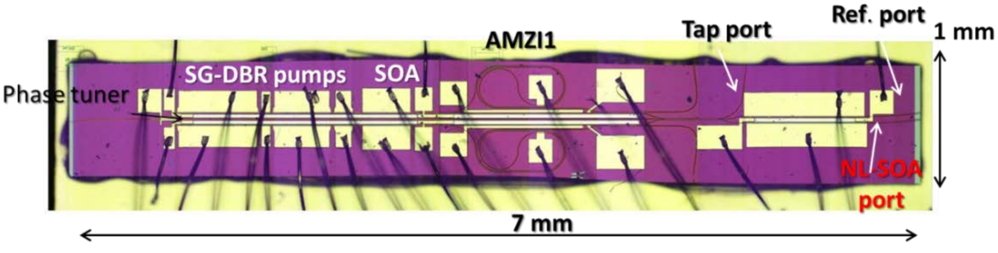
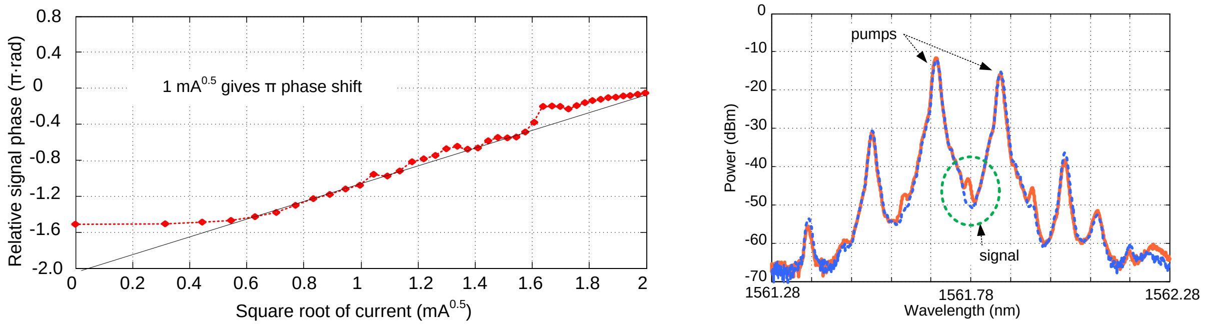


Fig. 1 Photo of the signal-degenerate dual-pumped PSA chip after wire-bonding

To monolithically integrate the single-chip PSA, we have chosen an InP/InGaAsP centered quantum well (CQW) platform with 10 quantum wells. Quantum well intermixing (QWI) technology [5] is used to define active and passive areas. More details about operation principle and chip fabrication can be found in [4].

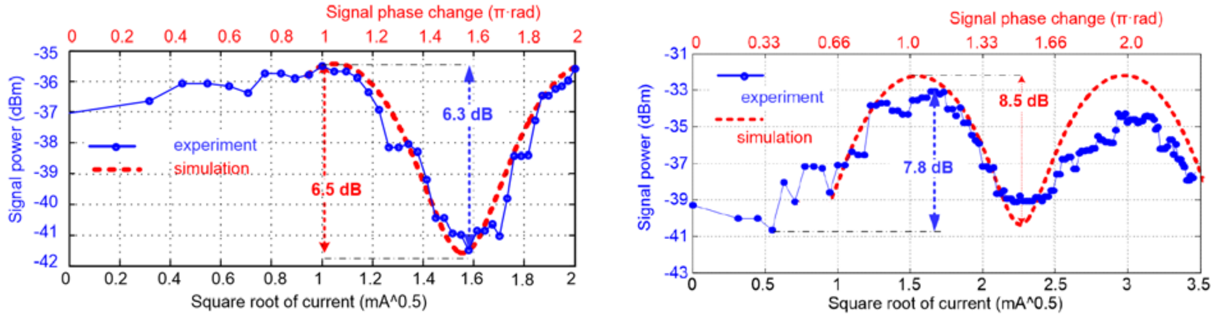
3. Experimental results and theoretical simulation

First of all, basic configurations for each PSA were conducted to make sure that 1) the two SG-DBR lasers can be injection locked; 2) the power distributions among the signal and the pumps are optimized; 3) only the signal phase is affected by the phase tuner; 4) no signal interference on the chip. Then, we measured the phase shift of the signal when we tuned the phase tuner current. The result is shown in Fig. 2(a) and overall, 1 mA$^{0.5}$ gives π phase shift of the signal. A delay in phase shift when the current was less than 1 mA could be caused by an N+ sheet charge that exists at the regrowth interface. The optical spectra at the output of the NL-SOA were measured when the signal phase was changed, as shown in Fig. 2(b). The signal was amplified or attenuated as the phase tuner current was adjusted. Such a current- or phase-dependent signal power change could be caused by the PSA.



(a) (b)

Fig. 2 (a) Measured relative signal phase change; (b) measured optical spectrum of the light wave at the output of the nonlinear SOA.



(a) (b)

Fig. 3 Comparisons of the measured PSA gain curve and the theoretical simulation. (a) one-period PSA gain curve with 6.3 dB experimental and 6.5 dB theoretical results; (b) two-period PSA gain curve with 7.8 dB experimental and 8.5 dB theoretical results.

To specifically demonstrate and evaluate the PSA, the measured relationship among the signal power at the output of the SOA, the square root of the phase tuner current and the signal phase are shown in Fig. 3(a). Overall, 1 mA$^{0.5}$ gives π phase shift of the signal and one period oscillation of the signal. Clearly, such a signal power oscillation over one π instead of 2π phase indicates that the signal power change was caused by the PSA. Another PSA chip was chosen to demonstrate multiple periods of a PSA gain curve, as shown in Fig. 3(b), and about 1.5 mA$^{0.5}$ gives π signal phase shift and one period oscillation of the signal. A model for multi-wavelength mixing in SOAs based on coupled mode equations [6] is developed and applied to the nonlinear SOA on the PSA chip. The simulation results are superposed on Fig 3. By comparing the experimental data and the theoretical curves, good agreement is achieved.

4. References

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