Wavelength Converter using Micro Transfer-Printed Optical Amplifiers on a Full SiPh Platform

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***Abstract*—We have integrated two semiconductor optical amplifiers (SOAs) in a Mach-Zehner interferometer (MZI) circuit on imec's iSiPP50G platform using micro-transfer-printing. We demonstrate wavelength conversion combining the dual-SOA's cross-gain and cross-phase modulation.**

***Index Terms*—Semiconductor optical amplifiers, Integrated optics devices, Wavelength conversion devices**

I. Introduction

Photonic integrated circuits (PICs) are bringing together a wider variety and greater number of optical and electrical components to achieve complex functionalities. Supported by mature CMOS technology, silicon photonics circuits are promising for high volume production of PICs with low cost and high uniformity. However, silicon, as an indirect bandgap material, cannot provide optical gain, which limits the scaling towards larger and more complex circuits. III-V materials are ideal for optical amplification. Several heterogeneous III-V-on-Si integration techniques have been proposed, such as flip-chip integration, wafer bonding, micro-transfer-printing (µTP) and hetero-epitaxial growth [1].

In this work, we used µTP to heterogeneously integrate pre-fabricated InP-based semiconductor optical amplifiers (SOAs) with a silicon based Mach-Zehnder interferometer (MZI). The circuits are fabricated using the standard imec's iSiPP50G platform, which supports passives, high-speed modulators and germanium photodetectors. Previously, we reported tunable III-V-on-Si lasers and transmitter designs based on the similar integrated amplifiers [2], [3]. Here, we embed the SOAs into a MZI and used the SOA-MZI circuit as a wavelength converter. The results show the cross-gain modulation (XGM) and the cross-phase modulation (XPM) of the SOAs. We extract the conversion bandwidth, as well as the mainlobe-to-sidelobe ratio (MSR).

II. Principle

With µTP, small pre-processed coupons of III-V material are placed inside local recesses of the iSiPP50G circuits (in close contact with the silicon layers), after which they are electrically connected with metal tracks. The process and III-V coupon design are discussed in [2], [3]. The processed chip is shown in the Fig. 1(a). The MZI circuit consists of a directional coupler (DC) splitter and combiner, with two balanced arms each containing an SOA. Each arm also has

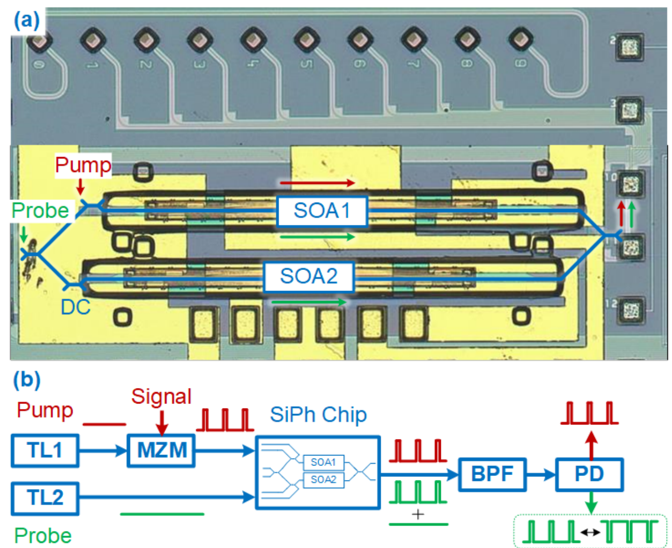

Fig. 1. (a) SOA-MZI circuit on chip. SOA: semiconductor optical amplifier; DC: directional coupler; (b) Schematic of the wavelength converter. TL: tunable laser; IM: intensity modulator; BPF: bandpass filter; PD: photodetector.

an additional DC allowing us to inject a signal into one arm only. Two SOAs are transfer printed to both arms, to provide optical amplification/absorption, nonlinearity as well as phase tuning. All the optical input/output ports are connected to a grating array for multiple-input multiple-output measurements. Fig. 1(b) shows the schematic of the wavelength converter. An external tunable laser (TL1) is used as pump light, whose intensity is modulated by an electrical square wave signal. The pump light is directly fed into the North arm (SOA1). The other tunable laser (TL2), the probe, is used coupled to the input of the MZI and passes through both SOAs on the chip. At the output, an external optical bandpass filter (BPF) allows us to select the pump or probe light going to the photodetector.

In this scheme, the pump light and part of the probe light are simultaneously fed into SOA1, so the probe light would be amplitude modulated and phase modulated by the pump. The other fraction of the probe light goes through SOA2 and then interferes with the modulated probe light in the DC combiner. If SOA2 is not driven or is reversed biased, it would show a high absorption and operate as a photodiode, and the probe light in the South arm would be lost. In this

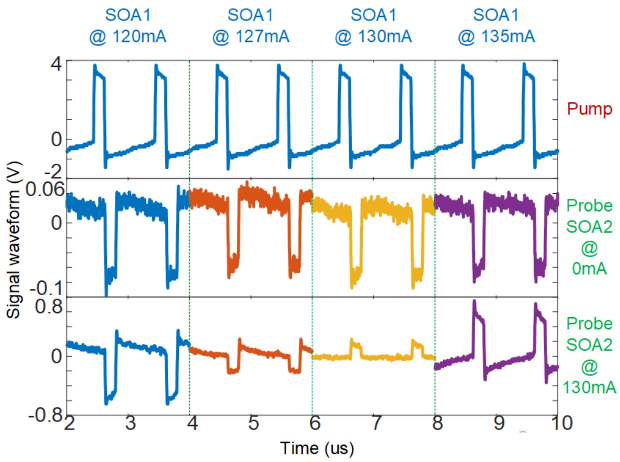

Fig. 2. Generated electrical waveform with pump light and probe light.

case, the wavelength conversion signal recovered from PD will be the XGM signal. If the SOA2 is driven in forward bias providing gain, the phase difference in the MZI is now determined by the drive currents of SOA1 and SOA2. Because of the interference, the modulated phase information can be converted to intensity. Thus the wavelength converted signal from the PD will be a combination of the XGM and XPM signal, and with the correct phase delay they can reinforce each other. The measurement results show that the combined signal can have a better mainlobe-to-sidelobe ratio (MSR) than the XGM-only signal.

III. Experimental results

We implemented the experiments using two external tunable lasers, an intensity modulator and a tunable BPF, as shown in Fig. 1(b). The pump laser was set at $1550\,\mathrm{nm}$, and the probe laser at $1555\,\mathrm{nm}$. A square wave with a duty cycle of 20% was used to modulate the pump light. A tunable optical filter (Finisar waveshaper) was used as the BPF. By passing the $1550\,\mathrm{nm}$ pump light, we can monitor the original waveform with an oscilloscope and use it as a reference, shown in the top plot in the Fig. 2. Then the BPF was set to $1555\,\mathrm{nm}$ and the wavelength converted signal was received by the PD and shown in the second and third plot of the Fig. 2. The second plot's waveform is acquired with the SOA2 switched off, which makes it an optical absorber. The injection current of the SOA1 has little effect on the waveform, while the reverted waveform verifies that this signal is generated by the XGM in SOA1. The third plot shows the additional effect of the phase difference of the MZI. By tuning the injection current of the SOA1 (the four different colors), the waveform can be flipped to the original state, indicating that it is generated by a combination of XGM and XPM in SOA1.

Then we applied a $2\,\mathrm{MHz}$ sinusoidal modulation on the pump light, and used an electrical spectrum analyzer to monitor the output of PD. The results are shown in Fig. 3(a). As can be seen, the XGM-only signal shows the worst MSR, while the combined XPM-XGM signals' MSR are approaching the

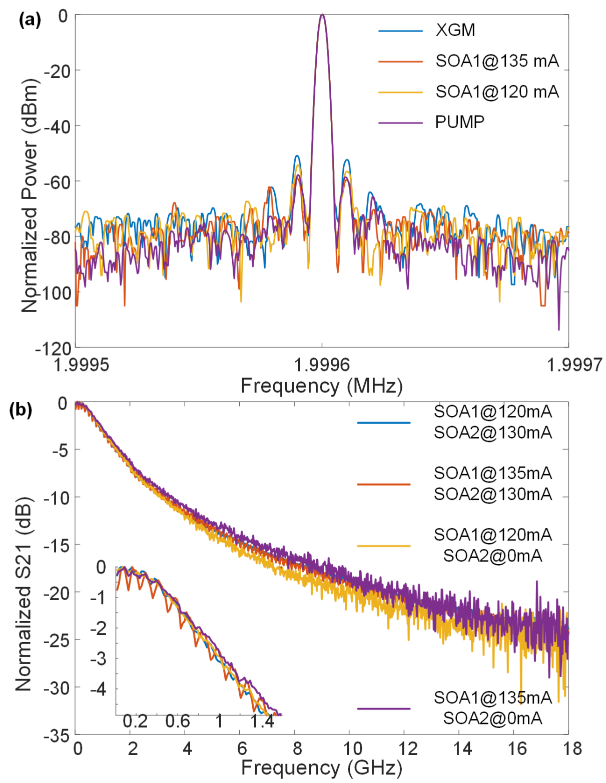

Fig. 3. (a) Spectrum of the wavelength converted signal and pump signal. XGM is SOA2 off and the others are SOA2 on; (b) Frequency response of the wavelength converter.

level of the pump signal. This means the SOA-MZI wavelength converter circuits performs better than a single SOA. The frequency responses of the wavelength converter are measured by a vector network analyzer in different driving states. The results are shown in Fig. 3(b), where we see that the curves are mostly overlapped. We also see that the $3\,\mathrm{dB}$ bandwidth of the fabricated SOAs are limited to $1\,\mathrm{GHz}$.

In conclusion, a µTP SOA-MZI based wavelength converter was implemented in ISIPP50G platform. While the proposed SOA-MZI can realize a wavelength conversion with a higher MSR than using a single SOA.

Acknowledgements

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