

All-Optical Wavelength Converter with InP Micro-disk Laser Integrated on SOI

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Abstract

An all-optical wavelength converter is demonstrated using an InP micro-disk laser on SOI. In this configuration, no extra probe beam is needed. The control power is as low as several micro-watts.

Introduction

Silicon photonics, especially based on the silicon on insulator (SOI) material system, is considered to be a promising technology for various photonic applications due to its potential for high-density integration of devices and compatibility with CMOS fabrication processes [1]. For future photonic networks, all-optical signal processing, e.g., wavelength conversion, is an important function [2]. Conventionally, wavelength converters are realized by employing a semiconductor optical amplifier (SOA) because of its strong and fast nonlinear effects [3]. All passive solutions are also possible based on, e.g., optical fibers [4], but ultra-high power is needed in these cases. It is believed that the high index contrast provided by SOI wire waveguides could help to enhance the non-linear response. Wavelength conversion has been demonstrated with a single SOI wire waveguide [5] or a ring cavity [6]. Still milli-watts of control power were required, due to the relatively weak non-linear coefficient of silicon.

In this paper, we propose an all-optical wavelength converter in SOI. The principle relies on the injection locking of a DC-biased, InP micro-disk laser (MDL), which is heterogeneously integrated on an SOI waveguide circuit [7]. This principle has also been applied to conventional Fabry-Pérot (FP) laser diodes [8] and vertical-cavity surface-emitting lasers (VCSEL's) [9] for similar functionalities. Other than the popular pump and probe scheme, no probe beam is needed in this configuration. The converted signal is the intrinsic lasing beam from the MDL. Wavelength conversion with a control power as low as several micro-watts is achieved.

Experiments and results

Figure 1 shows the experimental setup, as well as a microscope picture of the MDL used here (prior to

metallization). This MDL, with a diameter of $7.5\mu\text{m}$, was DC-biased at 3.5mA , which gave a single mode lasing power of $7.2\mu\text{W}$ in the underlying SOI waveguide. Figure 2 shows the corresponding lasing spectrum. The side mode suppression ratio is better than 25dB . For wavelength conversion, an external control laser was injected to the MDL through the SOI waveguide. This laser beam was tuned to the wavelength of the second highest spectral peak of the MDL, which is one free spectral range (FSR) away from the dominant lasing peak at the longer wavelength side. A modulator was employed to modulate this control laser for dynamic measurements. The output light was pre-amplified, and a band-pass filter was used to collect only the dominant lasing wavelength from the MDL.

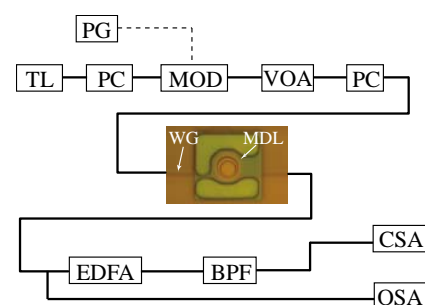


Figure 1: Experimental setup for wavelength conversion. TL: tunable laser, PC: polarization controller, MOD: modulator, VOA: variable optical attenuator, WG: SOI wire waveguide, EDFA: Erbium-doped fiber amplifier, BPF: band-pass filter, OSA: optical spectrum analyzer, CSA: communication signal analyzer, PG: pattern generator.

The working principle of the proposed wavelength converter is as follows. When the external control laser is on, the injected photons will couple into the micro-disk cavity, and the photons of the dominant lasing wavelength will decrease correspondingly. The

detected power is low in this case. While the control laser is off, the MDL is lasing normally. Thus, the signal carried on the external control laser will be inversely transferred to the dominant lasing wavelength of the MDL. Figure 2 also shows the static measurement result. As we can see, under the injection, the dominant lasing peak of the MDL is suppressed by about 20dB. The power level of the control laser in the SOI waveguide is estimated to be $6.4\mu\text{W}$. The active material included here helped to achieve such a low control power. With the DC bias current, the InP micro-disk cavity actually provides gain for the injected control laser. Although not high enough to achieve lasing at this wavelength, the gain can still help to increase the ratio of the circulating power in the micro-disk cavity to the injected control power in the SOI waveguide.

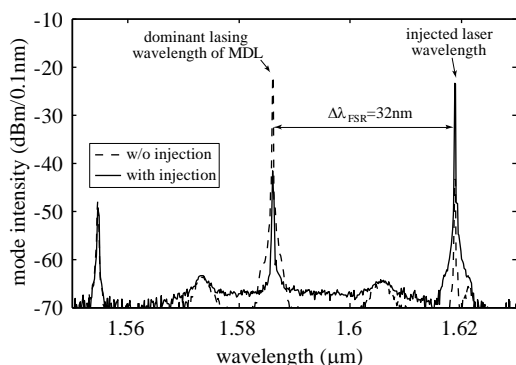


Figure 2: Output spectrum with and without injection.

The dynamic wavelength conversion is shown in Fig. 3, where the control laser was modulated with a square wave signal at 250MHz. The high-level power of the control laser was again $6.4\mu\text{W}$. The resulting extinction ratio of the converted signal is about 15dB, slightly less than the static result, due to the spontaneous emission from the EDFA. The rise and fall time are about 65ps and 130ps, respectively, thanks to the much faster carrier dynamics as compared to the all-silicon approach [6], where the transition time is typically of the order of nano-second.

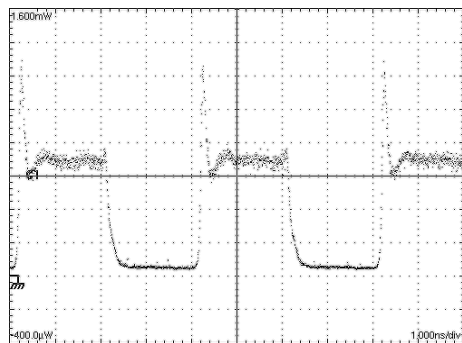


Figure 3: Response of the converted signal under rectangular modulation of the control laser at 250MHz.

Figure 4 shows the output eye diagram for an input signal of 5Gbit/s non-return to zero (NRZ) code with

$2^{31}-1$ pseudo random bit sequence (PRBS). An open eye was obtained. However, the signal-to-noise ratio is still low due to the relatively weak lasing power of the MDL ($7.2\mu\text{W}$; $1.8\mu\text{W}$ was coupled into fiber). This can be tackled by an improved MDL design with a higher output power, which can also help to increase the operation speed.

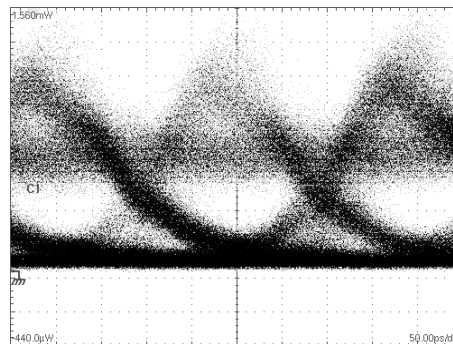


Figure 4: Measured eye diagram of the converted signal for a 5Gbit/s NRZ data pattern.

Conclusions

All-optical wavelength conversion has been demonstrated in SOI based on injection locking of a heterogeneously integrated, DC-biased, InP MDL. About 20dB extinction ratio of the converted beam has been achieved with a peak control power of only $6.4\mu\text{W}$. Dynamic measurements have shown that 5Gbit/s bit rate is feasible with this approach. Higher speed and better signal-to-noise ratio can be achieved by improving the output power of the MDL.

Acknowledgement

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