Stable Laser Without a Magneto-optic Isolator

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Abstract *A reflection-cancellation circuit on a silicon-on-insulator platform is used to stabilize a quantum well-distributed feedback (QWDFB) laser against real-time changing back-reflections. The demonstrated optical insertion loss is 2.5 dB for 15 dB of isolation/cancellation.*

Introduction

To leverage the well-established CMOS foundries that are used to manufacture the electronics chips at large-scale yet low-cost, photonic components (including the laser) should be integrated with state-of-the-art nanoelectronics in silicon. Following the laser, an optical isolator is required to protect the laser from destabilization, by allowing light to propagate in a single direction[1]; otherwise, when a fraction of the optical power exiting the laser flows back to it, the laser can become unstable[2]. Since silicon has a reciprocal lattice, these isolators are most practically realized by bonding magneto-optic materials on the silicon-photonic (SiP) chip[3]. However, besides being bulky, and expensive, magneto-optic materials are not compatible with silicon platforms, resulting in reduced yield. Other methods to realize optical isolation in silicon include non-linear[4] and spatio-temporatl[5],[6] effects, however, non-linear effects require high optical energies, and spatio-temporal modulators require high-speed drive circuits, suffer from high optical losses, and consume a large footprint, which compromises the form factor of a SiP product and increases the overall cost.

Here, we demonstrate an alternative method for stabilizing lasers against back-reflections. Instead of using an optical isolator, we use an electronic-controlled photonic reflections-cancellation circuit (RCC) to dynamically sense and cancel the light reflected back to the laser.

Design, Simulation, and Fabrication

Figure 1(a) shows a micrograph of the fabricated SiP chip that contains the RCC. The chip was fabricated on a 220-nm silicon-on-insulator (SOI) platform using 193 nm-deep ultraviolet lithography at the AMF foundry in Singapore. The RCC is an electronic-controlled optical circuit taps a portion of the laser's output and feeds it back to the laser with a phase adjustment such that it destructively interferes with the unwanted back-reflections. A simplified, free-space diagram of the RCC (including a reflection point) is shown in Figure 1(b). An important requirement of the RCC is its ability to automatically condition the amplitude and phase of the feedback signal accurately, such that the feedback signal destructively interferes with the unwanted reflections. The RCC consists of: 1) a tunable tap implemented by using a tunable Mach-Zehnder interferometer (MZI) (MZI2) with a phase shifter (PS1) above one of the MZI arms and a broadband adiabatic 3-dB couplers, 2) a phase-tunable reflector shifter implemented using a thermal phase shifter (PS2) and a waveguide looped to form a mirror, 3) four monitoring SiGe photodetectors (PDs) (PD1-PD4), and 4) an optical attenuator realized using an MZI (MZI3), and 5) an electronic circuit that controls the phase shifters based on the sensed currents from the four PDs. Based on the photocurrents read from PD1-PD4, the electronic circuit actuates PS1 to tap out a precise amount of light needed for canceling the unwanted reflected light, and then actuates PS2 so that the back-reflected signal is in antiphase with the unwanted reflections. A simplified illustration of the laser with a reflection point and the RCC is shown in Figure 1(b).

The laser's dynamic response was simulated according to the methods and using the parameters described in[2], where the laser rate equations were modified to include the RCC. Figure 1(c) shows the change in the average relative power going back to the laser and the maximum laser RIN as a function of PS2's phase. When R_{31}

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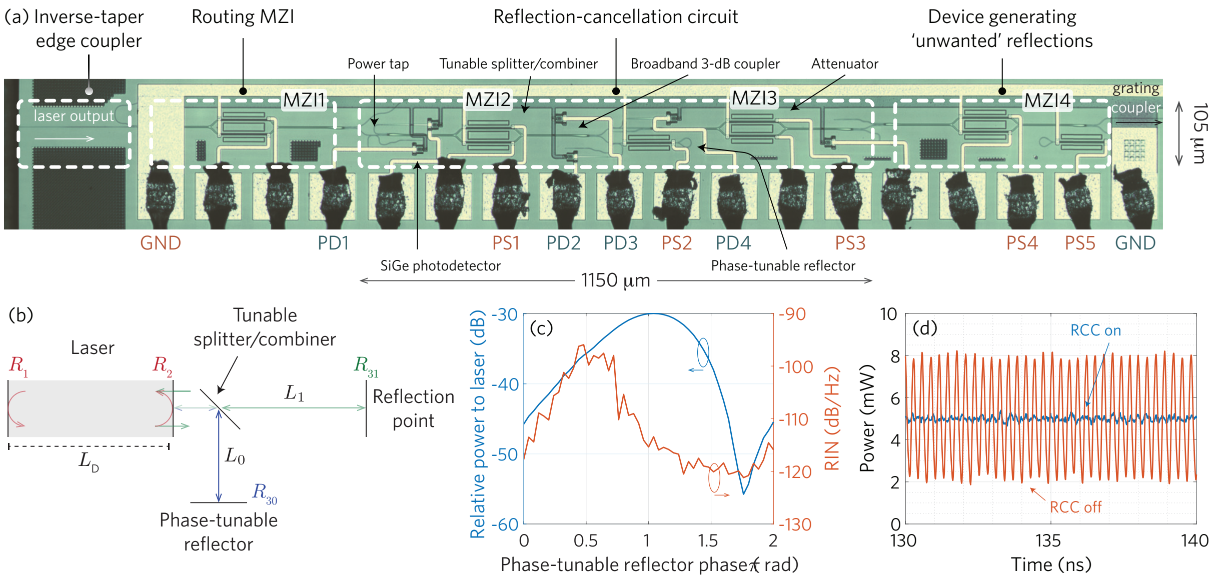

Fig. 1: (a) Microscope image of the fabricated SiP chip. (b) Illustration of a laser with a reflection point and the RCC. (c) Simulated relative power going back to the laser and the maximum relative intensity noise (RIN) as a function of the phase-tunable reflector's phase. (d) Simulated laser's temporal response, when the RCC is turned off (-30 dB reflections going back to laser) and when the RCC is on (PS2's phase is 1.76π rad, reflections are minimized to -55 dB as shown in Figure 1(c)).

is equal to R_{30} but in antiphase with each other, the power going back to the laser is minimal (-55 dB). This happens when PS2's phase is 1.76π rad. In such a case, the maximum RIN is minimal, at -120 dB/Hz. Figure 1(d) shows the simulated temporal response of the laser when the RCC is off (-30 dB of reflections going back to the laser) and when the RCC is on (PS2's phase is 1.76π rad). When the RCC is off, the laser self-pulsates and the maximum RIN increases to -80 dB/Hz. However, when the RCC is on, the laser's temporal response is stable with time ($\sim$5 mW) and the maximum RIN is reduced to -120 dB/Hz.

Experimental Results

To test the RCC, a commercial QWDFB laser without an isolator was used. The laser was biased at twice the threshold, 12 mA, producing 0 dBm optical power. A polarization-maintaining lensed fiber with an AR coating was then used to couple light into the TE mode of the on-chip waveguides. To assess the laser performance due to changes in the unwanted reflections when the RCC is turned on to stabilize the laser (RCC on) and when the RCC was not running (RCC off), a dynamic test was conducted by varying the unwanted back-reflections from the device reflector. Figure 2(a) shows a simplified illustra-

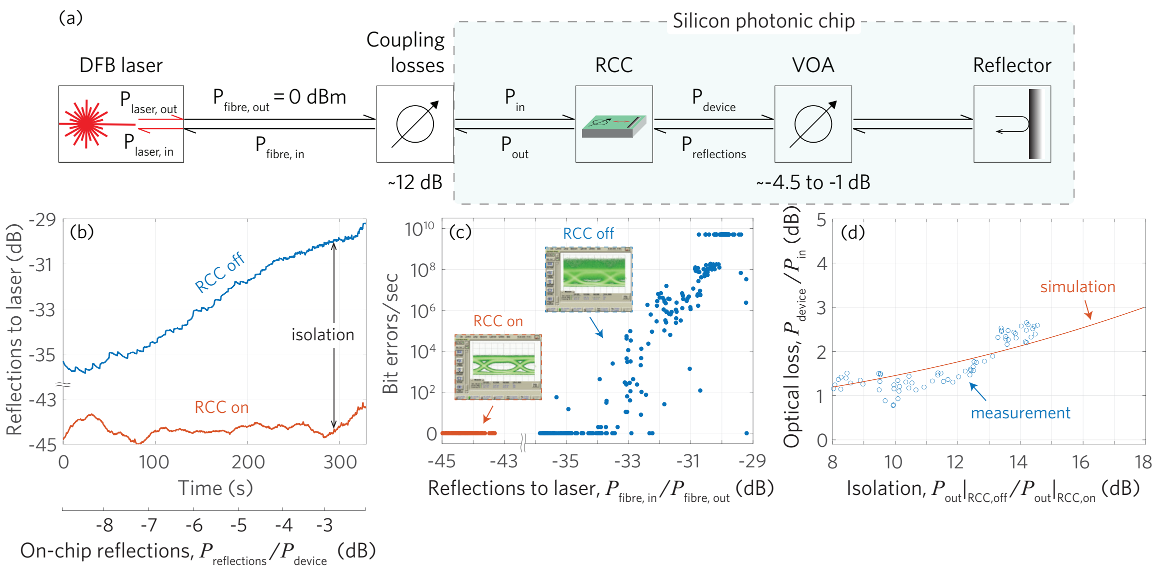

Fig. 2: (a) Simplified illustration of the measurement setup showing the optical power at different points in the link. (b) The reflections to the laser when varied with time, with the RCC off, and on, measured using PD1. (c) The measured bit errors for a 10 Gb/s PRBS-7 signal as a function of the reflections to the laser when the RCC was off and when it was on. (d) The measured optical insertion loss of the RCC (without the power taps losses) as a function of the optical isolation measured using PD4.

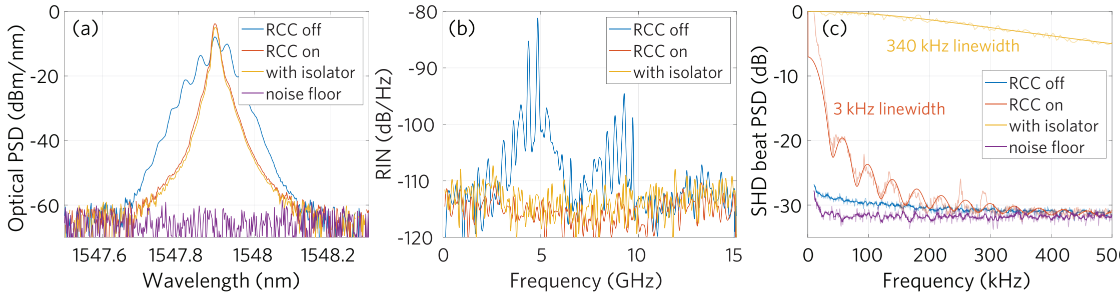

Fig. 3: (a) The optical spectrum of the laser, (b) the RIN of the laser, and (c) the self-homodyne (SHD) beat power spectral density (PSD) spectra indicating the linewidth of the laser with the RCC turned on, without the RCC, and with a magneto-optical isolator, In (c), the light lines are the measured spectra and the dark lines are drawn fitting to the measurement results using theoretical models of the SHD beat PSD lineshapes.

tion of the measurement setup showing the optical power at different points in the link. Accounting for the setup and lensed-fibre-to-chip coupling losses, the optical power on the chip going to the RCC (Pin) was ∼-12 dBm. The on-chip reflections were varied between -9 and -2 dB using an on-chip VOA and a reflector. Figure 2(b) shows the change in the on-chip reflections as a function of time, and the resulting back-reflections to the laser. To assess the laser's performance in real-time, -14 dB of the laser's output was coupled to an MZM that was driven using a 10 Gbps PRBS-7 signal and the modulated data was passed through an EDFA and a VOA into an RF PD. The output was then split using an RF power splitter and passed to an oscilloscope and an error detector for measuring the bit errors per second. Figure 2(c) shows the bit errors per second as well as the eye diagrams with varying reflections, when the RCC was off and when the RCC was turned on. As the reflections were varied and the RCC was off, noise at the '1' level resulted in high bit errors and a noisy eye. When the RCC was turned on, both phase shifters PS1 and PS2 were tuned to minimize the photocurrent read by PD1. Then, both phase shifters were varied simultaneously to minimize the photocurrent read by PD1 using a gradient-descent method. The eye was open with no bit errors as illustrated in the inset figures in Figure 2(c). The optical loss of the RCC as a function of the isolation ratio was measured using PD4 and is shown in Figure 2(d). This loss excludes the excess loss of the fabricated power taps (1.4 dB), where the power taps had a measured power coupling ratio of ∼15% for each of the two power taps tapping power to PD1-4.

The laser's optical spectrum, RIN, and linewidth were measured simultaneously after completing the dynamic tests but retaining the final values for the reflections going back to the laser for both the dynamic tests, i.e., $P_{\text{fibre, in}}/P_{\text{fibre, out}}$ ≈-29 dB with the RCC off, and $P_{\text{fibre, in}}/P_{\text{fibre, out}}$ ≈-44 dB with the RCC on. When the RCC was off, the optical spectrum in Figure 3(a) shows a broadened optical spectrum and the appearance of sidebands at the laser relaxation oscillation frequency. These sidebands occur simultaneously as indicated by the peaks shown in the RIN spectrum in Figure 3(b). The laser linewidth was also measured using the SHD technique[7]. The SHD shows a beat PSD that is close to the RF spectrum analyzer (RFSA) noise floor. When the RCC was turned on, the optical spectrum showed a single lasing peak as indicated in Figure 3(a). To compare the laser performance with the RCC and the laser performance with an off-chip isolator, we added a fiber-optic isolator between the laser and the lensed fiber, and re-measured the laser optical spectrum, RIN, and linewidth. The optical spectrum and RIN of the laser when the RCC was turned on is comparable to when an isolator was used. However, the linewidth of the laser was narrower, ∼3 kHz, when the RCC was on, compared to when an isolator was present, ∼340 kHz, which is due to the feedback-induced linewidth reduction[8].

Conclusions

We demonstrated a stable laser against back-reflections using a reflection-cancellation circuit made on a planar silicon photonic chip using a foundry process without the deposition of any additional materials. The circuit provided up to 15 dB of cancellation at the expense of 2.5 dB of optical loss. The RCC further enhances the QWDFB laser performance by reducing its linewidth by a factor of 100, down to 3 kHz.

Acknowledgements

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