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Direct Modulation of a Hybrid III-V/Si DFB Laser with MRR Filtering for 22.5-Gb/s Error-Free Dispersion-Uncompensated Transmission over 2.5-km SSMF

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Abstract *Error-free and penalty-free transmission over 2.5 km SSMF of a 22.5 Gb/s data signal from a directly modulated hybrid III-V/Si DFB laser is achieved by enhancing the dispersion tolerance using a silicon micro-ring resonator.*

Introduction

Directly modulated lasers (DMLs) are considered as a promising alternative to external modulation for short-reach applications, including access and data-centre networks, where cost, energy consumption and footprint considerations are of critical importance. Due to the expansion of data traffic, such low cost transceivers are required to operate at higher speed than the currently available 10 Gb/s. These networks will be upgraded soon to operate at 25 Gb/s or more. Even if high-speed DMLs have been demonstrated[1-3], they are limited by their low extinction ratio (ER), frequency chirp and reduced dispersion tolerance. In fact, the most challenging issue in the implementation of high-speed directly modulated transceivers is the high susceptibility of 25 Gb/s signals to fiber dispersion at 1550 nm. .

To overcome these challenges, chirp managed lasers (CMLs), where the DML is followed by optical filtering, have been introduced[4,5] and successfully demonstrated[6-8]. While these first CML demonstrations made use of discrete filters, a flip-chip implementation of a CML operating at 10.7 Gb/s was demonstrated in [8]. However, this technique requires time-consuming mechanical alignment and CMLs would clearly benefit from a fully integrated solution that would ease the assembly of the transmitter module and reduce the footprint of the transmitter chip. In this respect, the silicon-on-insulator (SOI) platform is promising for the cost-effective implementation of photonic integrated circuits (PICs) and the effectiveness of the use of silicon micro-ring resonators (MRRs) as optical filters for chirp management has already been successfully proved with discrete edge-emitting distributed feedback (DFB) lasers[9,10]. Recently, thanks to the progress of integration of III-V materials on the SOI platform, a fully integrated III-V/Si hybrid CML has been successfully demonstrated at 10 Gb/s[11]. Furthermore, electronic equalisation and power consuming forward error correction (FEC) circuits should be avoided in short-reach applications since they introduce undesirable latency.

In this work, for the first time to our knowledge, we demonstrate an all-on-silicon transmitter operating at 22.5 Gb/s by directly modulating a III-V/Si hybrid DFB laser followed by a silicon MRR filter. Error-free (BER<10^{-9}) direct detection on-off keying (OOK) signal transmission over 2.5-km of standard single mode fiber (SSMF) is demonstrated without need for dispersion compensation or FEC.

Laser structure and fabrication

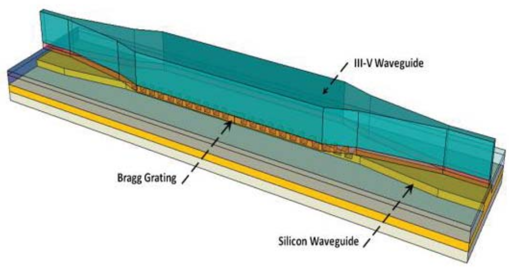

Fig. 1: DFB laser structure.

The hybrid DFB laser was fabricated by wafer-bonding of III-V material on silicon. As shown in Fig. 1, a double taper structure is used to couple efficiently the light between the silicon and III-V waveguides. A Bragg grating with a period Λ = 240 nm is etched into the silicon waveguide under the III-V waveguide. The laser provides single mode operation with side mode suppression ratio of more than 40 dB. The fabricated DFB laser was soldered on a submount and a bias current threshold of

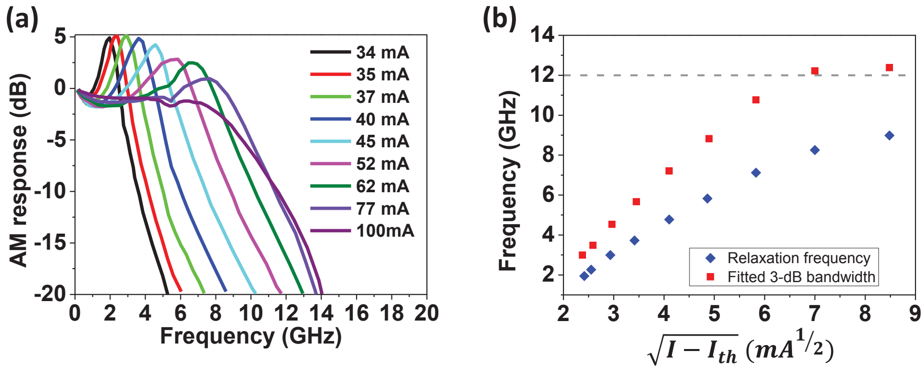

Fig. 2: (a) Measured small signal amplitude responses. (b) Relaxation oscillation frequency and 3-dB bandwidth obtained by fitting the AM response data.

28.5 mA was measured. The small signal amplitude modulation (AM) responses of the DFB laser have been measured for different bias currents from 34 mA to 100 mA and are shown in Fig. 2(a). From these S_{21} curves, the relaxation oscillation frequencies and the 3-dB bandwidths of the DML have been extracted and plotted versus the square root of the difference between the bias current and the threshold current (Fig. 2(b)). The modulation bandwidth exceeds 12 GHz for bias currents above 100 mA.

MRR structure and fabrication

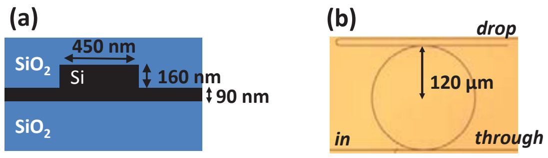

Fig. 3: (a) MRR structure and (b) MRR microscope picture.

The MRR was fabricated on an SOI wafer with a top silicon thickness of 250 nm and a 3-µm buried silicon dioxide layer. Electron-beam (EB) lithography and inductively coupled plasma reactive ion etching were used to define the micro-ring structure shown in Fig. 3(a). Plasma-enhanced chemical vapor deposition (PECVD) was then used to deposit a silica cladding top layer. The rib waveguide has a depth of 160 nm and its width is 450 nm. A microscope picture of the device is shown in Fig. 3(b). Grating couplers are implemented at the *in*, *through* and *drop* ports to couple light in and out of the MRR and the *in*-to-*through* total insertion loss of the MRR away from resonance is 9 dB. The diameter of the MRR is 120 µm, which corresponds to a free-spectral range (FSR) of

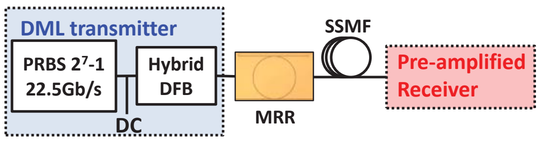

Fig. 4: Experimental setup: DML transmitter, MRR filter for ER and dispersion enhancement, transmission fiber (removed for B2B measurements) and pre-amplified receiver.

100 GHz. This parameter was designed in view of future deployment in combination with laser arrays for WDM applications. The measured Q-factor is 3.8×10^4.

Experimental setup

The setup is shown in Fig. 4. The hybrid III-V/Si DFB laser was biased at 130 mA, corresponding to a 3-dB bandwidth of approximately 12 GHz, and directly modulated at 22.5 Gb/s with a 2^7-1 non-return-to-zero (NRZ) pseudo-random binary sequence (PRBS) signal generated by a bit pattern generator with a peak-to-peak voltage of 3 V. The optical signal at 1546.5 nm was then filtered by the MRR for ER and dispersion tolerance enhancement. The MRR was mounted on a thermal control stage for thermal tuning of the resonance allowing the suppression of part of the low-frequency content of the optical signal spectrum, as shown in Fig. 5. After MRR offset filtering, the signal was transmitted over SSMF and received with a standard pre-amplified receiver followed by an error analyser for bit-error-ratio (BER) measurements and a sampling oscilloscope for eye diagram recording. The transmission performance was compared based on BER measurements for 0-, 2- and 2.5-km SSMF without and with the MRR filter.

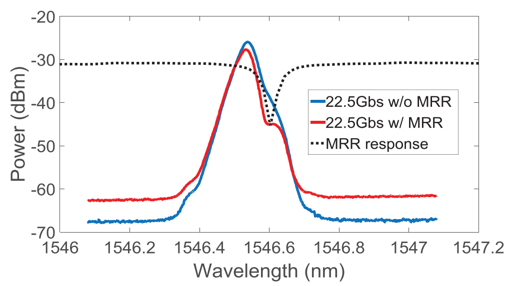

Fig. 5: Signal spectra at 22.5 Gb/s with and without the MRR filter. The MRR transfer function is also shown.

Experimental results

The eye diagrams are shown in Fig. 6 for back-to-back, 2-km and 2.5-km SSMF transmission. They are all measured for a received power of -15 dBm. The back-to-back (B2B) eye

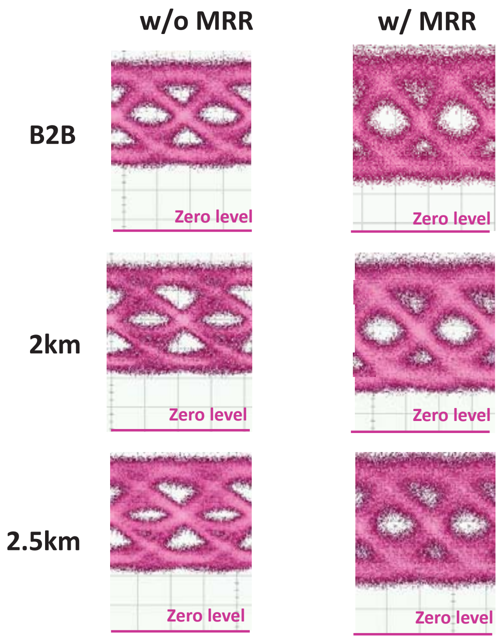

Fig. 6: Eye diagrams (10.5 mV/div) at 22.5 Gb/s with and without MRR filter for B2B, 2-km and 2.5-km SSMF.

diagrams show an ER increase from 2 dB (without MRR) to 3 dB (with MRR). After transmission, however, the eye diagrams of the filtered signals are clearly less distorted compared to the unfiltered ones, showing the enhanced dispersion tolerance of the transmitter with the MRR filter. This behaviour is confirmed by the BER performance reported in Fig. 7. The B2B receiver sensitivity (BER= 10^{-9}) is improved by more than 3 dB thanks to the MRR filtering. After transmission over SSMF, the accumulated dispersion degrades the quality of the received signal with the DML signal showing an error floor at BER=10^{-4}. FEC would thus be required at the receiver, thereby increasing latency and energy consumption. By using the MRR filter, error-free performance can be achieved up to 2.5 km with around 4 dB of power penalty compared to the back-to-back filtered DML, which however corresponds to no penalty when compared with the unfiltered DML back-to-back.

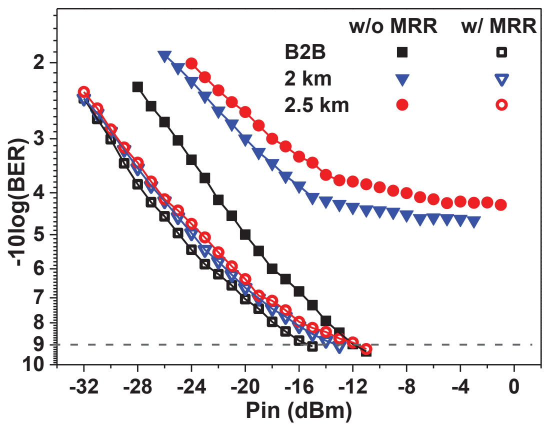

Fig. 7: BER at 22.5 Gb/s with and without MRR filter for B2B, 2-km and 2.5-km SSMF.

Conclusions

A hybrid 22.5-Gb/s III-V/SOI filtered DFB DML operating at 1546.5 nm was demonstrated, showing an enhanced dispersion tolerance. Error-free transmission over 2.5-km SSMF was achieved without the use of electronic equalisation techniques, FEC or dispersion compensation, showing no penalty with respect to the DML B2B performance.

Acknowledgements

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