Multiple Wavelength Generation from a Mode Locked Silicon Evanescent Laser

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Introduction

Silicon photonic elements have clear advantages in low cost manufacturing, potential integration with CMOS electronics, and in manufacturing low loss passive elements with highly repeatable performance. Detectors and modulators have also been demonstrated with high speed performance up to 40 Gb/s using silicon photonics [1, 2]. Optical sources for silicon based devices are another important area of research since they are required for fully integrated silicon optical communications [3-5]. Silicon evanescent lasers are one attractive option to achieve this task since they are highly scalable and can have performance approaching traditional III-V lasers [3].

For some silicon photonics applications such as massive parallel computing, large amounts of data should be transmitted using separate channels. For example, 90 wavelength channels can allow each core in a 10-core computing system to communicate with each of the others. In applications that require very large numbers of channels, it may be much more difficult or even impossible to generate enough channels with separate lasers. Instead a single integrated mode locked laser (MLL) can be designed to emit short pulses that have a corresponding wide optical spectrum of phase correlated modes, allowing it to be used as a multiple wavelength source [6-10] for a modulator array. This might provide significant cost savings and design simplicity. Since the optical modes are phase correlated, other functions such as OCDMA transmission and arbitrary optical waveform generation are also possible using such a source [11]. The ability to integrate an MLL with passive silicon components such as arrayed waveguide gratings (AWGs) is particularly desirable for these multiple wavelength source applications.

Recently, we made an initial demonstration of mode locked lasers using a silicon evanescent laser approach [5] and here we show improved performance and potential application as multiple wavelength WDM sources. We present results from a hybrid silicon evanescent mode locked laser (ML-SEL) that creates a comb of over 100 optical modes within 10-dB of the peak mode output power. We examine the linewidth and OSNR of several longitudinal modes across the spectrum of this comb. We also investigate results from injecting CW laser seed light into the ML-SEL to stabilize the modes.

Device and experimental setup

The ML-SEL has a similar structure to the 10 GHz device that was described in reference [5] and was fabricated using the same techniques. The device has a 4,160 µm-long gain region and an 80-µm saturable absorber (SA) region, which are separated by a 10-µm electrical isolation region. The gain section was biased at 1.03 A. A 15 dBm RF signal at 10.26 GHz is sent to the SA section along with a -2.5 V DC bias using a bias T. The device is temperature stabilized at 13°C and the output light was taken from the front facet, opposite the SA, using a lensed fiber.

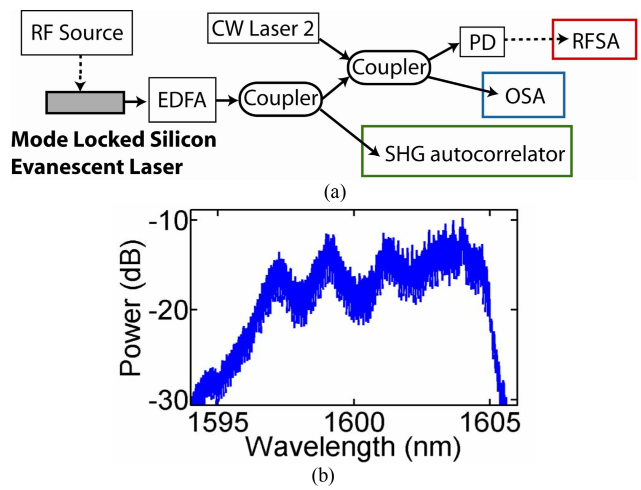


Fig. 1. (a) Experimental setup. (b) Optical spectrum of the 10-GHz ML-SEL with 0.06 nm resolution, which can not resolve the individual modes well.

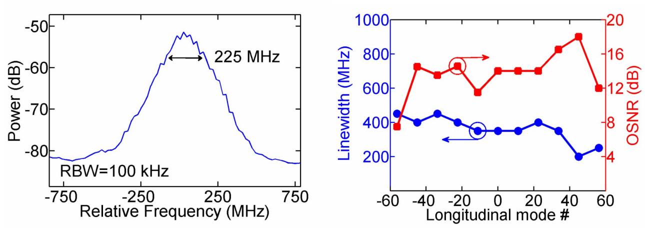
The experimental setup is shown in Fig. 1 (a). The output of the ML-SEL is sent into an EDFA and then split to a second harmonic generation autocorrelator (SHG) and another coupler. At this second coupler, the signal is combined with a stable (<0.1 pm resolution), narrow linewidth (<100 kHz) CW probe signal (CW laser 2) used to measure the individual modes of the ML-SEL. The output of this coupler is sent to a 0.06 nm resolution optical spectrum analyzer (OSA), and a 40 GHz photodetector (PD) connected to a DC-41 GHz RF spectrum analyzer (RFSA).

Experimental Results

The optical spectrum is shown in Fig. 1 (b). The 10-dB spectral width is 9 nm, with over 100 modes spaced by 0.089 nm. The pulsewidth was 5.8 ps and the average output power was -2.8 dBm in fiber (after 6 dB coupling loss). When the probe laser is combined with the ML-SEL output, beat notes

978-1-4244-1783-4/08/$25.00©2008 IEEE

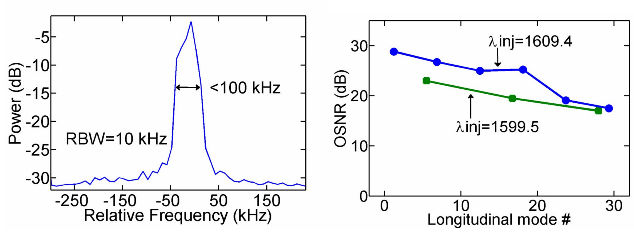
are created between the probe wavelength and the longitudinal modes of the ML-SEL. By looking at the RF spectrum of these two signals combined, we can determine the linewidth [7, 10] and OSNR [10] of the ML-SEL modes from the beat notes, shown in Fig. 2. The resolution of this linewidth measurement is determined by the linewidth of the probe laser, which is less than 100 kHz. We define the OSNR as one half of the ratio of the peak level to the bottom level of the comb as measured on the RFSA, which corresponds to the visibility of the longitudinal mode in the optical domain [8]. This measurement provides a lower limit of the OSNR because the RF spectrum between the modes also contains noise from beating between other harmonics of the CW probe laser with other ML-SEL modes. Under these operating conditions, the linewidths and OSNRs are not suitable for long distance communications, but the modes should be sufficient for short reach applications such as chip-chip or chip-network WDM.



(a) (b)

Fig. 2. (a) RF spectrum of the CW signal beat together with the ML-SEL output with 100 kHz resolution. (b) OSNR and 3-dB linewidth versus ML-SEL mode number. Mode 0 corresponds to 1600 nm.

To improve the results, a stable 0 dBm (in fiber) CW seed signal at 1609.41 nm was injected into the back of the ML-SEL. This reduced the 10-dB spectral width to ~2.5 nm, but drastically improved the other characteristics. The linewidth was reduced to that of the CW input signal (~100 kHz) across 30 modes, with an example shown in Fig. 3 (a)**.** Fig. 3 (b) shows that the OSNR was improved by approximately 10 dB. Again, this number is likely limited by the measurement capabilities. Similar results were obtained for seed wavelengths as low as 1599.5 nm.



(a) (b)

Fig. 3. (a) RF spectrum showing the linewidth under CW injection to the ML-SEL at 1609.4 nm, with 100 kHz resolution. (b) OSNR versus mode number for 2 different injected wavelengths. Mode 0 corresponds to the injected CW wavelength.

Conclusions

We have tested a 10-GHz mode locked silicon evanescent laser as a potential multi-wavelength source for WDM applications. The output contains over 100 modes within 10-dB output power, each having a linewidth below 500 MHz and OSNR better than 10 dB. For applications such as on-chip, chip-chip, or short reach WDM, the output directly from this MLL is likely to be sufficient. For applications with more stringent linewidth, OSNR, and RIN requirements, injection locking can produce more stable longitudinal modes. In this case 30 MLL modes have an OSNR better than 18 dB, and linewidth equal to that of the CW input.

Future designs utilizing ring cavities [12] or integrated mirrors can precisely determine the cavity length and thus channel spacing. These designs also allow for integration with many other components such as AWGs, modulators, or even DFB lasers [13] for injection locking, enabling a fully integrated multi-wavelength WDM source on silicon.

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Acknowledgements

We thank J. Shah, M. Haney, H. Park, K.-G. Gan, and R. Jones for useful discussions. We also thank H.-H. Chang, Y.-H. Kuo, and O. Raday for assisting with device fabrication. This research was supported by DARPA/MTO and ARL and by Intel.