Narrow Line Width Injection-locked III-V-on-silicon Mode-locked Laser

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Coherent optical orthogonal frequency division multiplexing (OFDM) systems are highly desirable for spectrally efficient optical communication systems. To implement such systems, an optical frequency comb source that can generate an array of narrow line width lines with a fixed phase relation is required. Integrating mode-locked lasers (MLL) on a silicon photonics chip could tackle these problems. However, to meet the demanding requirements of coherent communications, the MLLs need to have both a low timing jitter and its longitudinal modes need to have a narrow optical line width.

We propose a solution based on the injection locking of an integrated MLL with a modulated narrow line width continuous wave (CW) source. In this paper, we report a reduction of the longitudinal modes' line width from several MHz to 50 kHz for a 4.71 GHz repetition rate MLL. This line width is narrow enough to enable coherent data transmission with advanced modulation formats. Coherence between more than 50 longitudinal modes and the CW source is experimentally confirmed. Due to the low optical power that is needed to lock the MLL, the system could be completely integrated on a single chip. The experiments were performed on a linear cavity colliding pulse III-V-on-silicon MLL [1]. The device geometry is shown in Fig. 1. The saturable absorber (SA) (100 µm long) and the optical amplifiers (2 x 430 µm) are implemented in the III-V-on-silicon section, placed in the middle of the cavity. The remainder of the cavity is formed by two silicon spiral waveguides of each 0.7 cm to reach a repetition rate of 4.71 GHz. The cavity mirrors are formed by distributed Bragg reflectors (DBR) providing 50% reflectivity. The laser emits in the L band. More details on the MLL fabrication and dimensions can be found in [1]. For the injection locking experiments 100 mA current is injected in the optical amplifiers and the SA is reversed biased at -1.3 V, resulting in 6 mW of waveguide coupled laser output power. In case of passive mode-locking and free running operation, the 3 dB optical line width of the longitudinal modes of the MLL is several MHz and the RF line width of the fundamental tone was found to be 55 kHz. A fiber-coupled CW source with a 50 kHz optical line width is injected in the MLL through a fiber-to-chip grating coupler. The wavelength of the seed coincides with the centre of the MLL spectrum. The on-chip CW seed power is 0.1 mW. To control the repetition rate of the MLL, the seed laser is modulated at the repetition rate of the MLL. This results in a sub-hertz 3 dB RF line width. To assess the coherence of the comb lines, a commercial fiber frequency comb source (Menlo Systems) is used to interfere with the III-V-on-silicon MLL. The commercial frequency comb lines are spaced f_{probe} = 100 MHz. The beat notes of the CW seed source with the commercial fiber comb source have a line width of around 100 kHz.

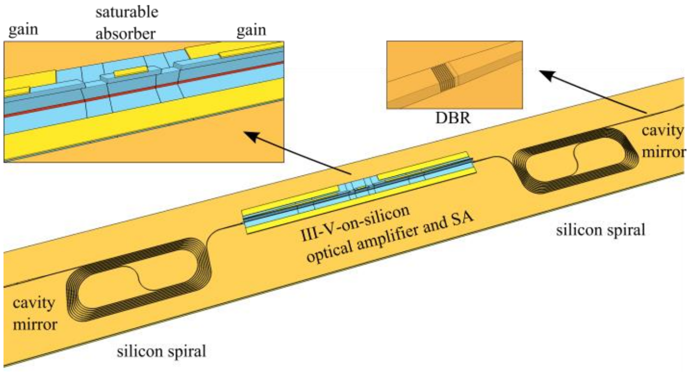

Fig. 1. Illustration of the linear cavity colliding pulse mode-locked laser.

The output of the comb laser is first sent through a filter with a 3 dB bandwidth of 0.1 nm and a tunable centre wavelength, such that one can scan over the different lines of the MLL (spaced 40 pm apart) without probing them all at the same time. Next, the combined output is sent to a photodetector connected to an RF spectrum analyzer to record the beat notes.

Many different beat notes will be generated, With f_a being the distance between a MLL longitudinal mode and the nearest neighbor comb line, $f_{MLL}$the repetition rate of the MLL and f_{probe} the repetition rate of probe comb source, we can find beat notes at:

$$\pm f_a + m f_{MLL} + l f_{probe} \qquad m, l \in \mathbb{Z} \tag{1}$$

The beat notes of the MLL with the filtered probe comb are depicted in Fig.2. We can distinguish 12 lines that correspond to equation (1). Line 1a and 1b result from two fiber frequency comb lines spaced f_a and $f_{probe} - f_a$ from the same MLL comb line. Line 2a and 2b originate from the beating of the probe comb with the neighboring MLL comb line and so on. From the Lorentzian fit of the beat notes line widths <100 KHz are obtained. This proves that the probed MLL lines are coherent with the seed laser. When sweeping the probe comb over the MLL lines, narrow beat notes are measured from 1578.3 nm to 1580.4 nm, indicating that 55 MLL lines are coherent with the seed laser.

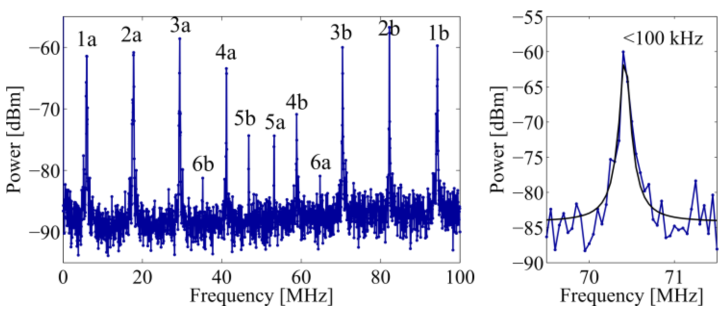

Fig. 2. Beat notes recorded at the electrical spectrum analyzer and a Lorentzian fit of one of the beat notes with a 3 dB line width <100 kHz (Resolution Bandwidth: 50 kHz).

References

[1] S. Keyvaninia, S. Uvin et al., *Narrow-linewidth short-pulse III-V-on-silicon mode-locked lasers based on a linear and ring cavity geometry*, Optics Express, 23, 3221–3229, 2015