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42 nm wide coherent frequency comb generated by a QW based integrated passively mode-locked laser

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Abstract: An experimental study of an InP extended cavity passively mode-locked ring laser which shows extra wide frequency comb generation is presented. An increase of the bandwidth to over 40nm at -20dB level is observed. Confirmation of the coherence and measurements of the relative time delay across the comb is presented.

Keywords: laser, modelocking, frequency comb, photonic integration

1. INTRODUCTION

Integrated passively mode-locked semiconductor lasers (PMLs) are compact and robust sources for coherent frequency combs and short optical pulse generation. They become especially attractive when active-passive integration is used. This technology enables one to combine passive components, such as passive waveguides, electro-optical modulators, on-chip mirrors, couplers with amplifiers and lasers on the same chip. In this paper we present a passively mode-locked laser fabricated through a generic active-passive integration platform which uses quantum wells as an active core. In this technology a large variety of photonic integrated circuits can be realized, including those which require a source of coherent frequency combs. Previously we have demonstrated that a 20 GHz extended cavity ring colliding pulse geometry laser which produced a wide frequency comb of 11.5 nm wide at the 3 dB level [1]. However, even though 11.5 nm is a record value for QW based PMLs, it is still below the results obtained from quantum dash (Qdash) PMLs. In [2] a frequency comb of more than 16 nm bandwidth generated by a Qdash laser was demonstrated. In this work we present a 12 GHz ring passively mode-locked laser realized in the same fabrication platform as in [1] but improved series resistance of electrical contacts (from 3.8·10⁻³ Ω·m to 2.9·10⁻³ Ω·m) and a longer saturable absorber (SA). We show that a QW based PML laser can generate an optical comb 42 nm wide at the 20 dB level. This is wider than results published for Qdash lasers. While the optical comb spectrum displays power variations, the comb is completely coherent, which we confirmed through several measurements performed in the time and frequency domains. Therefore, it can be used in various applications, for example terahertz generation

2. 12 GHZ PASSIVELY MODE-LOCKED LASER GEOMETRY AND EXPERIMENTAL CHARACTERIZATION

The laser was fabricated using the COBRA active-passive integration platform within a multi-project wafer run. The laser was designed using a library of basic building blocks with a predefined layer stack. Figure 1 (a) shows a mask layout of the 12 GHz ring symmetrical colliding pulse PML which consists of two semiconductor optical amplifiers (SOAs) sections of 325 µm each, a 40 µm SA, shallowly and deeply etched passive waveguides and a 2x2 multimode interference coupler (MMI). The total length of the cavity was 7 mm. In order to avoid reflections from the edge of the chip the output waveguides were tilted by 7°. Intracavity reflections were avoided by using angled active-passive interfaces, adiabatically curved deep waveguides, an optimized MMI structure and optimized shallow to deep waveguide transitions.

The PML was operated under various current and voltage levels provided to the SOAs and the SA respectively. The light emitted by the laser was collected using an anti-reflection coated lensed fiber which was connected to other equipment through an optical isolator. The optical output power, optical spectrum, RF spectrum of a 50 GHz
photodiode signal, autocorrelation trace and time trace obtained using a sampling oscilloscope (SO) were recorded. Figure 1 (b) shows the optical spectrum for the SOA current range $I_{SOA} = 30$ to $100$ mA at $U_{SA} = -3.4$ V. The threshold was observed at 36 mA. Fiber coupled optical power and SA photocurrent reached 1 mW and 13 mA respectively at 100 mA injected current. As it can be noticed from Fig. 1 (b), an increase in the injected current leads to a broadening of the optical spectrum due to an appearance of spectral components at the short wavelength side. When the SOA current was set at 59 mA the optical bandwidth measured at 20 dB level reached 42 nm, which exceeds optical bandwidth demonstrated by Qdash and QD based PML. The Fig 1 (d) shows the RF spectrum measured at the same operating conditions. The 3 dB linewidth of the fundamental RF peak is 200 kHz. The pulse formation was confirmed by the measurement of the autocorrelation (AC) and time trace using a 30 GHz sampling oscilloscope (SO). The AC trace width at these operating conditions was 2 ps. A further increase of the injected current did not lead to further broadening of the optical spectrum. The structure of the optical comb can be caused by the presence of self-phase modulation effects [3]. This effect increases when pulse intensity is increased. From the AC traces we found that the pulse peak intensity did not increase with the current above 60 mA. This is consistent with no further change of shape of the optical comb.

However, for many applications of frequency combs a coherency across the spectrum is required. In order to check the coherency several measurements were done. The laser output was sent through a tunable band pass filter (BPF) of 1.5 nm bandwidth. The BPF covers around 10 longitudinal modes. We recorded the AC trace, RF spectrum of the photodiode signal and SO time trace of the signal of these selected modes. Across the whole comb the AC traces show pulse formation. In the RF domain the peak at 12 GHz was also present across the whole tuning range. The spectral dependency of the height of the RF peak followed that of the optical spectrum envelope. The RF peak position showed an increase of 200 kHz across the comb, which might be attributed to a temperature drift, since the measurements took around one hour.

The measurements of the time traces using the SO at various filter positions also confirmed pulse formation across the comb. Moreover these measurements allowed to characterize a relative time delay between the longitudinal modes. Figure 2 shows the optical spectrum (orange) and the relative time delay (blue) measured at $U_{SA} = -3.5$ V and $I_{SOA} = 90$ mA. The total time delay over 25 nm is 2.3 ps, which corresponds to a chirp of 0.09 ps/nm. The optical path from the laser to the SO included a total length of 4 m of single mode fiber. The dispersion of such fiber is 17 ps/(nm·km). The dispersion of the InP/InGaAsp output waveguide can be neglected. Therefore the contribution to the time delay variation over the comb from the optical components outside the laser cavity is 1.7 ps.

3. CONCLUSION

In this paper we demonstrate that QW based passively mode-locked lasers can generate coherent optical combs which are wider than the reported combs of Qdash PMLs. First, the laser was characterized at the range of the currents injected to the SOA. This study shows a broadening of the optical comb up to 42 nm at -20 dB level. The coherency of the optical comb was subsequently confirmed by characterization of the spectrally filtered output signal in the time and frequency domains. In addition a relative time delay of 2.3 ps across the comb was measured. We attribute the reported improvement of the PML performance in comparison with the results presented in [1] to the improved quality of the electrical contacts and longer SA.

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REFERENCES

