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# Broadband Optical Coherent Frequency Comb from a Monolithic InGaAsP/InP Extended Cavity Ring Mode-Locked Laser

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Passively mode-locked lasers (PMMLs) became a subject of interest not only due to the high applicability in the various fields requiring short optical pulses [1] but also as a broadband source for wavelength division multiplexing [3] and high-speed gas spectroscopy [4]. Monolithically integrated semiconductor PMLLs are of particular importance because of their compactness, robustness and low cost. In this work we report on the generation of one of the widest coherent optical combs produced by a quantum well (QW) ring PMLL. The device was realized on our Indium phosphide (InP) active-passive integration platform [2].

The ring laser (Fig. 1(a)) is formed with straight and curved passive waveguides, two semiconductor optical amplifiers (SOA), a reverse biased amplifier section that operates as a saturable absorber (SA) to support mode-locked operation, and a multimode interference coupler which couples out the clockwise and counter clockwise optical waves. The 30  $\mu\text{m}$  long SA section is integrated between two SOA sections of equal length (375  $\mu\text{m}$ ). The ring cavity thus formed is symmetrical with respect to the SA section.

The widest optical spectrum we have observed is depicted in Fig. 1 (b). It is recorded with a 20 MHz resolution optical spectrum analyzer. The gain sections are DC biased at 154.8 mA total current and the SA reverse bias was -2 V. The spectrum exhibits a (longitudinal) multi-mode structure with a free spectral range of 19.889 GHz which corresponds to the fundamental resonance of the 4 mm long ring cavity. The spectrum features a 3dB bandwidth of 11.5 nm (17 nm when measured at -10 dB) and an extinction ratio (contrast ratio) from the background in excess of 20 dB.

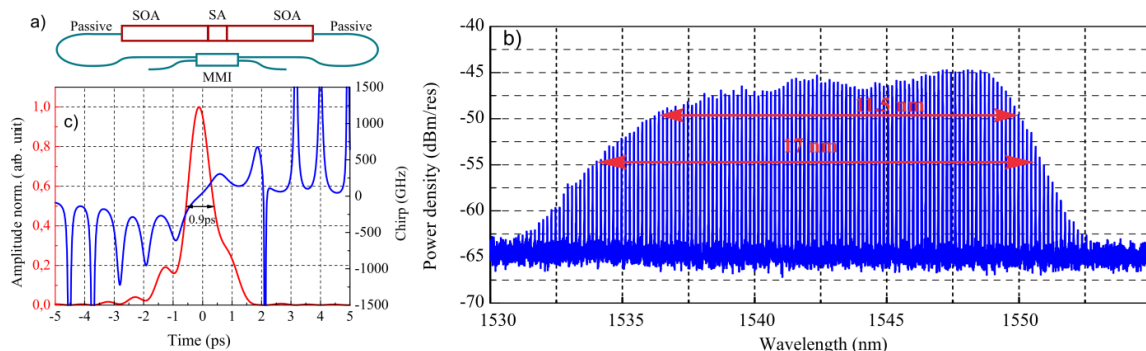


Fig. 1 (a) Sketch of symmetrical ring mode-locked laser. (b) Optical comb featuring 11.5 nm of FWHM bandwidth ( $\sim 17$  nm at -10 dB) recorded from PMLL biased at  $I_{\text{BIAS}}=154.8$  mA and  $U_{\text{SA}}=-2$  V. (c) Optical pulse profile measured using the step heterodyne method. The RMLL is biased at  $I_{\text{BIAS}}=90$  mA and  $U_{\text{SA}}=-2$  V.

The laser output pulses were characterized a.o. using a step heterodyne pulse characterization scheme [5]. In this technique, the PMLL optical pulse is combined with a tunable laser source (TLS) which is tuned over the spectrum of the PMLL. The beating frequencies between TLS and two PMLL longitudinal modes are detected using a fast photodiode and a real-time oscilloscope (50 GHz bandwidth). The phase and the amplitude profiles in time can be extracted from these data. A pulse duration of 900 fs and a chirp of 350 GHz were observed as shown in Fig. 1(c). In conclusion, we have demonstrated integrated PMLLs with a 3 dB bandwidth of 11.5 nm, which is the widest reported optical comb generated from QW based PMMLs. This work was supported by the NRC Photonics program and the PARADIGM FP7 project.

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