Optically Coupled Mode-Locked Laser Array for Spectroscopy in InP Generic Integration

Mu-Chieh Lo*
University College London
London, UK, and
Universidad Carlos III de Madrid
Leganés, Spain
*mlo@ing.uc3m.es

Christoph Weber, Dominik Auth,
Patrick Fiala, and Stefan Breuer*
Institute of Applied Physics,
Technische Universität Darmstadt
Darmstadt, Germany
*stefan.breuer@physik.tu-darmstadt.de

Guillermo Carpintero*
Department of Electronic Technology,
Universidad Carlos III de Madrid
Leganés, Spain
*guiller@ing.uc3m.es

***Abstract*—We propose a two-element mode-locked laser array operating at 1.56 µm. Optical pulses with 14.5-ps width, spectral bandwidth exceeding 7 nm, and RF line width of 260 kHz at 12.448 GHz are experimentally reported.**

Keywords— Diode laser arrays, Mode-locked lasers, Photonic integrated circuits

I. INTRODUCTION

Dual-comb spectroscopy (DCS) allows for high-speed sweeping of spectral fingerprints, which requires two optical frequency comb generators (OFCG) with slightly different comb separation frequencies and comb lines spectrally correlated to those of each other [1]. Such mode-locked OFCGs with intra-cavity phase shifters can offer further reliability, tunability and accessibility on a photonic integrated circuit (PIC) [2]. In this paper, we demonstrate two 12.5-GHz repetition rate mode-locked lasers (MLL) in 6.5-mm ring cavities which are optically coupled on a single chip using an active-passive generic foundry approach [3]. Laser emission characterization results including optical spectra, radio-frequency (RF) spectra and autocorrelation (AC) traces are presented.

II. DEVICE DESCRIPTION

The layout and photo of the proposed two-MLL array PIC are shown in Fig. 1(a) and Fig. 1(b), respectively. Each symmetric ring cavity is 6.5-mm long corresponding to a repetition rate of 12.5 GHz, and is composed of one 30-µm saturable absorber (SA), two 400-µm amplifier sections (SOA, semiconductor optical amplifier), 4000-µm electro-optic phase modulator (EOPM) in four sections and other passive components. Between these active sections electrical isolation sections are inserted to avoid unwanted current flows. The deeply etched passive s-shaped and arc-shaped waveguides with 100-µm bending radii form the ring geometry. One 3-dB 2x2 MMI coupler guides the optical signals towards the cleaved facet. Out of the cavities, one MMI coupler combines the optical signal from each MLL followed by two output waveguides with/without booster amplifier SOA, respectively.

III. RESULTS AND DISCUSSION

The lower MLL (Ring1) is characterized by forward biasing its two SOA sections with a gain current (I_{SOA}) and biasing the SA with a reverse voltage (V_{SA}). The signal from the waveguide output (OUT) without booster is collected with a lensed fiber and sent to optical/electrical spectrum analyzers and autocorrelator. Fig. 1(c) shows the optical spectrum for I_{SOA} = 110 mA and V_{SA} = 1.9 V, with a -3-dB comb width exceeding 7 nm despite the >5-dB dip at 1560 nm. Fig. 1(d) shows the AC trace for the same operation, the deconvoluted pulse width amounts to 14.5 ps assuming a Gaussian shape.

The -3-dB spectral comb width is depicted in dependence on I_{SOA} = 60 – 180 mA and V_{SA} = 1.5 - 2.6 V in Fig. 2(a). Within V_{SA} = 1.6 - 2.4 V and I_{SOA} = 70 – 130 mA, multimode lasing spectra are found whereby the spectral bandwidth can

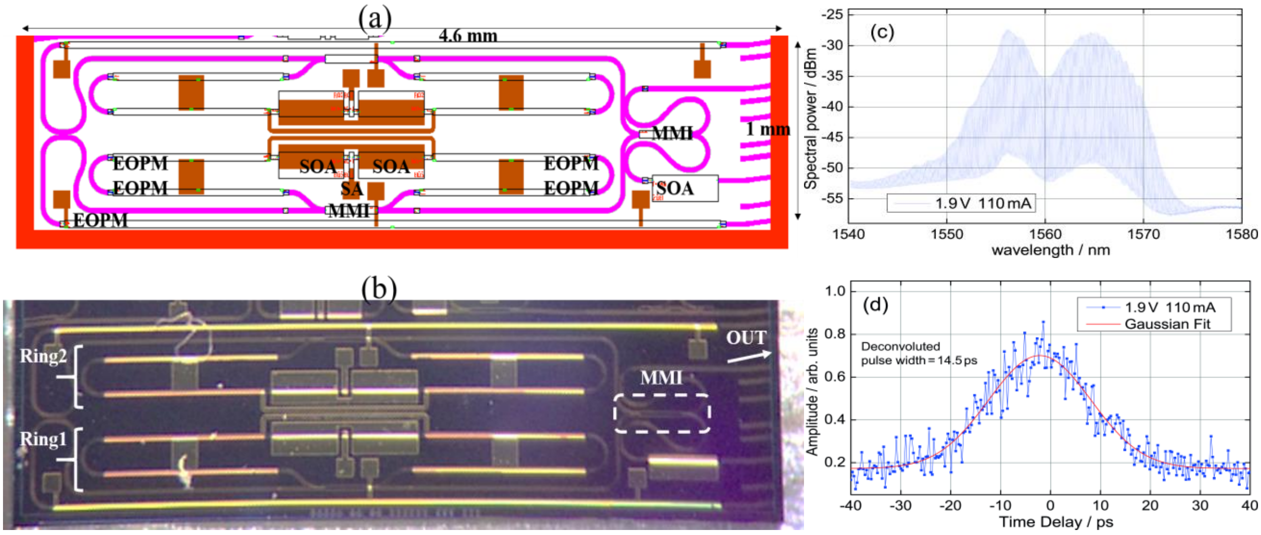

Fig. 1: (a) Layout of the dual-MLL PIC. (b) Photo of the dual-MLL PIC. (c) Measured optical spectrum, and (d) Measured AC trace for I_{SOA} = 110 mA, V_{SA} = 1.9 V. operating at 1.5 µm.

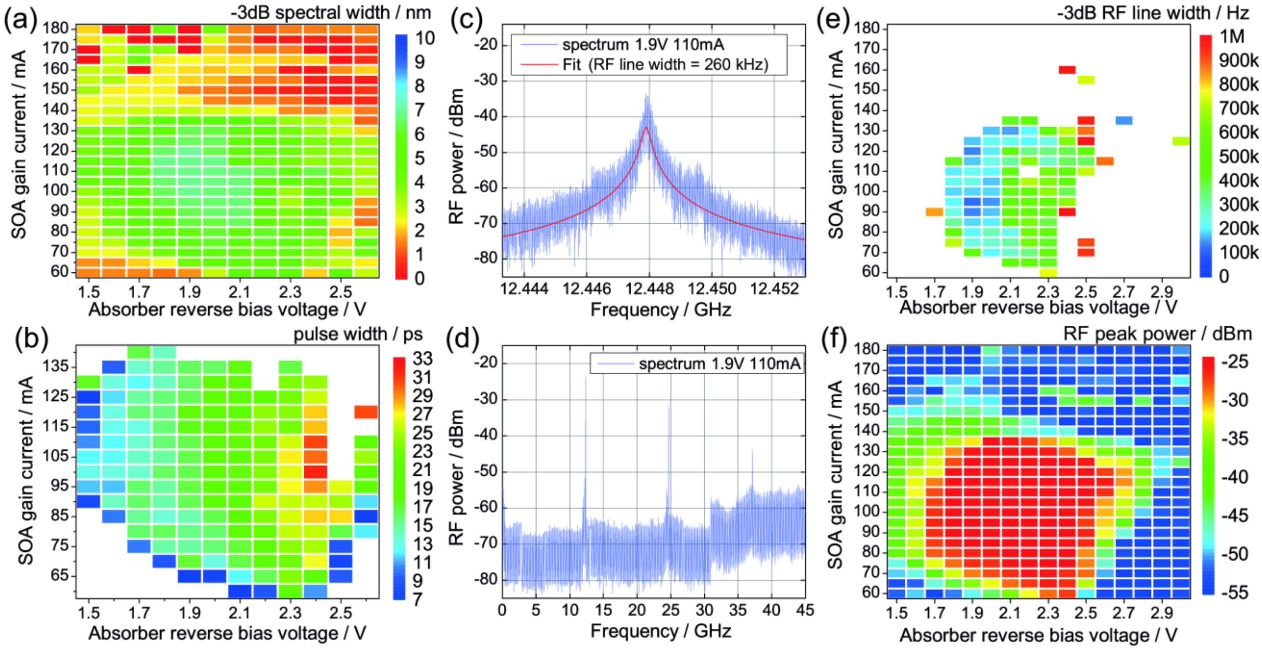

Fig. 2: (a) Map of -3-dB spectral bandwidth, and (b) Map of deconvoluted pulse width. (c) Zoom into fundamental RF beat tone, and (d) Wide-span RF spectrum for I_{SOA} = 110 mA, V_{SA} = 1.9 V. (e) Map of -3-dB RF line width. (f) Map of RF beat tone power.

exceed 4 nm. For the biasing regime of I_{SOA} = 80 - 120 mA and V_{SA} = 1.8 - 2.1 V, the spectral bandwidth can exceed 6 nm. Fig. 2(b) presents the deconvoluted pulse width map where the shortest pulses (7 - 8 ps) are found at the mode locking region boundary while the longest pulses (31 - 32 ps) at I_{SOA} = 100 mA and applied voltage V_{SA} = 2.4 V ranging from 7 to 35 ps for the various operating injection current I_{SOA} and applied voltage V_{SA}.

For the aforementioned bias condition I_{SOA} = 110 mA and V_{SA} = 1.9 V, we identify a narrow RF signal at 12.448 GHz with a signal-to-noise ratio of 40 dB and an RF linewidth of 260 kHz as revealed in Fig. 2(c). The full-span spectrum depicted in Fig. 2(d) clearly shows the harmonic tones. Similarly, the -3-dB RF line width and RF beat tone power are color-coded for I_{SOA} varied from 60 to 180 mA in increments of 5 mA and V_{SA} from 1.5 to 3.0 V in increments of 1.0 V in Fig. 2(e) and Fig. 2(f), respectively.

Within the range of I_{SOA} = 70 – 130 mA and V_{SA} = 1.8 - 2.3 V, the collected RF line width is below 600 kHz and the RF power exceeds -30 dBm. Within the range of I_{SOA} from 70 to 130 mA and V_{SA} from 1.8 to 2.1 V, the collected RF linewidth is below 300 kHz.

IV. CONCLUSION

We have developed a MLL array PIC in an InP generic integration technology and experimentally demonstrated the mode-locking behavior of a ring laser in the two-element array. 7-nm-wide optical frequency combs have been generated with a comb spacing of 12.448 GHz. The RF tone exhibits a line width of 260 kHz, and for the same bias condition we have achieved a pulse width of 14.5 ps. Given that the coherent comb bandwidth is sufficiently broad, further investigations for spectral tuning are of significant interest. Hybrid mode locking and controlling the intra-cavity EOPMs for both ring MLL will shortly be performed.

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