Colliding Pulse Mode-Locked Laser Diode using Multimode Interference Reflectors

C. D. Gordon[1], R. Guzman[1], A. Jimenez[1], X. Leijtens[2], G. Carpitero[1]

[1] *Universidad Carlos III de Madrid, Leganes, Madrid, Spain*
ingcarlosgordon@gmail.com, guiller@ing.uc3m.es
[2] *COBRA Research Institute, Eindhoven University of Technology, Eindhoven, Netherlands*
X.J.M.Leijtens@tue.nl

Abstract: We present a novel fully monolithic Colliding Pulse Mode-Locked Laser Diode (CPML) using Multimode Interference Reflectors (MMIRs) to create the laser resonator. We demonstrate experimentally for the first time to our knowledge the Colliding Pulse mode-locking of a laser using MMIRs by observation of the Optical Spectrum and by measuring the frequency spacing between the modes. This component is a promising candidate for Stable Millimeter-Wave Generation in ultra-wideband wireless communication links. Multimode Interference Reflectors are very versatile components that allow avoiding the required cleaved facets to operate.

Introduction: A cost effective technique to increase the data rate of wireless communication systems into multi-gigabit per second is to increase the carrier wave frequency into the millimeter wave region, from the E-band (60 to 90 GHz) to beyond[1]. The challenge to generate signals at this frequency range can be overcome using Microwave Photonic techniques which combine the best of the electronic with the best of photonic techniques[2]. Several reported wireless communication links operating above 100GHz use photonic generation of the carrier frequency. Mode-locked laser diodes (MLLD) are have been successfully used in wireless link demonstration operating at 60GHz[1] and 120GHz[3]. In the latter, the frequency of the pulse train was doubled by an optical clock multiplier (OCM). In the OCM, the pulse train was divided into the two separate legs of a Mach–Zehnder interferometer, and one leg provided a pulse delay.

An alternative approach to increase the repetition rate of a MLLD is by applying Colliding Pulse Mode-locked (CPML) which allows generating higher order harmonics of the cavity round trip frequency, depending on the relative position of the saturable absorber with respect to the mirrors and the length of the resonator[4]. In one hand, if the Saturable Absorber (SA) is located at the middle of the cavity Length (L/2) the CPML is classified as Symmetric Colliding Pulse Mode Locking (S-CPML) which produces optical pulses at twice the cavity round trip frequency. On the other hand, if the Saturable Absorber is shifted from the midpoint toward one facet at an integer fractional position of the cavity length (L/n), it is called Asymmetric Colliding Pulse Mode Locking (A-CPML) which generates the optical pulses at a frequency that is n times the repetition rate defined by the length of the resonator. Besides, the essential components to form the cavity of the resonator are the Multimode Interference Reflectors (MMIRs) which are novel on-chip mirror structures.[5] These are 2-port 50%/50% equal ratio reflection/transmission MMIR.

Device Description: The layout of the S-mCPML where the Saturable Absorber (SA) is located at the middle of the cavity Length (L/2) is depicted in Fig. 1(a). In the A-CPML the Saturable Absorber is located in a position (L/4) toward one faced because we want to generate a harmonic at four times the
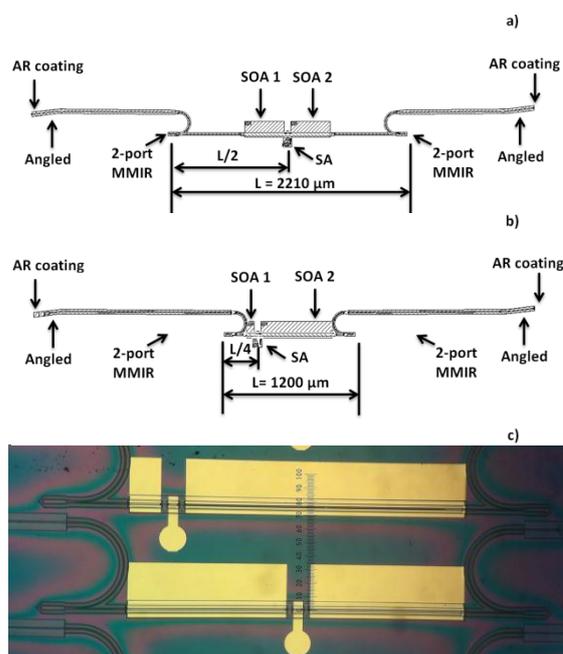

Fig. 1. (a) Symmetric mCPMLLD.
(b) Asymmetric mCPMLLD. (c) Microscope Photograph of the Photonic Integrated Circuit.

repetition rate.   Fig. 1(b) shows the layout of the A-CPML.

The device was fabricated in a Multi-Project Wafer (MPW) run for InP-based Photonic Integrated Circuits (PICs), carried out in the clean room at the COBRA Research Institute of the Eindhoven University of Technology (NL). The total length of the cavity in the S-CPML is 2210 μm which allows getting a frequency spacing of 18.67 GHz and the harmonic of 37.34 GHz established by the colliding pulse at midpoint (L/2) of the cavity. The A-CPML with a length of 1200 μm allows obtaining a mode spacing of 34.58 GHz and the harmonic of 138.32 GHz defined by the colliding pulse at one quarter (1/4) point of the cavity. A microscope photograph of the device is shown in Fig. 1(c).

Characterization: The evolution of the optical spectrum of the S-CPML while the current is increased and saturable absorber reverse voltage is fixed at V_{SA} = -3 V is depicted in Fig. 2(a). The light output versus current curve of the S-CPML is shown in Fig. 2(b), where a threshold current of 36 mA is observed. From the comparison between the L-I curve and the optical spectra map we identify different regions of operation of the device. At threshold, the device turns-on as a Fabry-Perot laser, exhibiting lasing on few modes. At 60 mA, the device enters into a colliding pulse mode locked state, up to 100 mA. To confirm the CPML state, the optical pulses were measured on an APE Pulse-Check background-free auto-correlator.

The optical spectrum of the S-CPML in the Colliding Pulse mode-locked state recorded at $I_{SOA\ T}$ = 60 mA (I_{SOA1} = I_{SOA2} = 30 mA), V_{SA} = -3 V, Central wavelength 1560nm and span 40nm in a Yokogawa AQ6370B optical spectrum analyzer is shown in Fig. 3. Inset it shows the mode spacing of 18.67 GHz and the harmonic of 37.34 GHz. We get wide bandwidth which value is BW = 935.53 GHz (7.49 nm) measured at -3 dB. Besides, the A-CPML continues in further studies in order to demonstrate the colliding pulse operation.
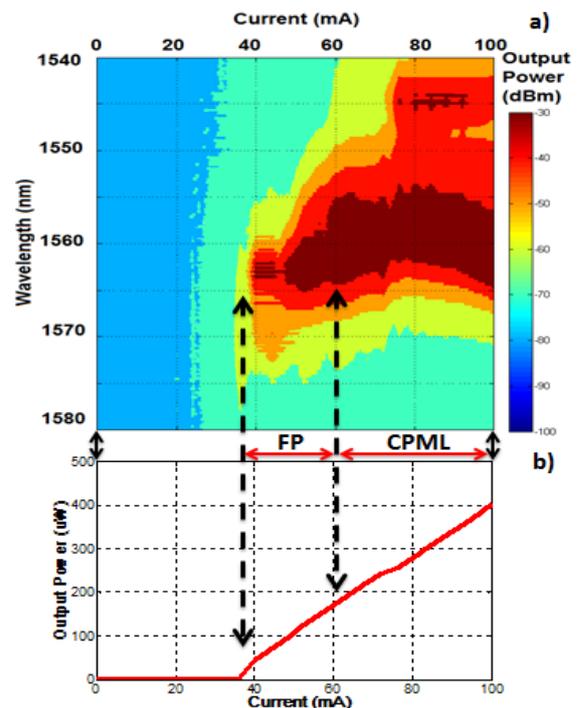

Fig. 2. (a) Evolution of the Optical Spectrum. (b) The Light output versus Current (L-I) curve
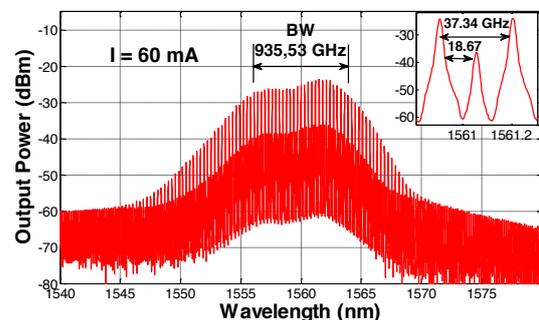

Fig. 3. Optical spectrum of the Symmetric mCPMLLD. Central wavelength 1560nm, span 40nm. Inset it shows the frequency mode spacing.

Conclusion: In summary, the present work is the first demonstration of the fully monolithic Colliding Pulse Mode-Locked Laser Diode reporting experimental data of mode spacing of 18.67 GHz and the harmonic of 37.34 GHz for the Symmetric Colliding Pulse Mode Locking Laser. The device is a novel design that integrates multimode interference reflectors so it does not require cleaved facets, and can be freely located on a Photonic Integrated Circuit (PIC).

References

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