# Monolithically integrated widely tunable laser and electro-absorption modulator in a generic InP integration platform

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*We present the operation of a monolithically integrated widely tunable laser and an electro-absorption modulator that were fabricated with an identical active layer stack. We have designed, fabricated and characterized this device for the first time in the COBRA generic integration platform for the operation at 1.55 µm. The tuning of the laser is achieved using a three stage, voltage-controlled, intra-cavity Mach-Zehnder interferometer filter. The modulator's small footprint of 100 µm yielded a 9.4 dB static extinction ratio, which, together with its electro-optical bandwidth of 13 GHz, allowed on-off-keyed data modulation for a 10 Gbps bit rate.*

## Introduction

A generic InP-based active-passive integration platform provides the possibility of monolithic integration of various components, with a targeted use depending on the material properties. Different platforms have emerged offering a wide range of functionalities [1] [2]. One of them is the COBRA integration platform, on which we will focus here, providing the possibility of diverse chip designs, mainly for use in telecommunication at 1.55 µm. For a transmitter or a receiver topology, all of the functionalities can be incorporated on a single photonic integrated chip, which is of great interest for the communication world. The possibility of having a laser source with a modulator brings us to the design of a transmitter. In case of an electro-absorption modulator (EAM), we ideally want the tunable laser source with a sufficient bandgap offset between the laser and the modulator, in order to minimize the insertion loss of the EAM. This would increase the complexity of the fabrication, as such a modulator would require an extra regrowth step. To avoid this, there have been attempts in operating a DFB laser and an electro-absorption modulator with the same active layer stack [3] [4]. Other devices include a widely tunable laser source integrated with an EAM [5], in order to have more operation freedom by choosing the detuning wavelength. Finally, different techniques have been used to integrate the two structures, such as butt-joint regrowth in [5] and selective area growth [6].

In this work we present the design, fabrication and characterization of a widely tunable laser source and an electro-absorption modulator, in the COBRA integration platform. The widely tunable laser achieves a single mode operation over its full tuning range and has been characterized and described in [7]. Its integration with an electro-absorption modulator, described in [8], will be presented in the following sections.

## Monolithic photonic integrated circuit

The COBRA active-passive generic integration platform has a predefined layer stack for both active and passive devices, to allow different users to use the same platform. On this platform a number of standard building blocks are available. The structures in the active layer stack are: amplifiers, electro-absorption modulators (EAM), photodetectors, and the ones in the passive stack: electro-optical modulators, simple waveguides – straight or curved, multimode interference (MMI) couplers, multimode interference reflectors (MIR) and arrayed waveguide gratings. The combination of these structures allowed us to design a widely-tunable extended-cavity ring laser together with an electro-absorption modulator. The semiconductor optical amplifier (SOA) inside the laser and the EAM have the same active layer stack. This leads to a much simplified fabrication process, as there is no need for extra regrowth of the modulator's layer stack. However, the layer stack of the laser and the modulator cannot be separately optimized, which will impact the performance.

The mask layout of the photonic integrated circuit (PIC) is shown in Figure 1. It comprises the following components: a 1-mm-long SOA section for providing the gain; asymmetric Mach-Zehnder interferometers (AMZI) in a serial configuration to provide a wide tuning of the ring laser; a MIR section in the laser cavity to ensure its unidirectionality; an EAM which is connected to the output of the laser via a passive waveguide. The length of the modulator section is 100 µm. In addition, there are 30-µm-long sections before and after the active region of the EAM, which ensure electrical isolation of the structure. An antireflection (AR) coated facet and an angled output waveguide effectively suppress reflections back in the modulating region.

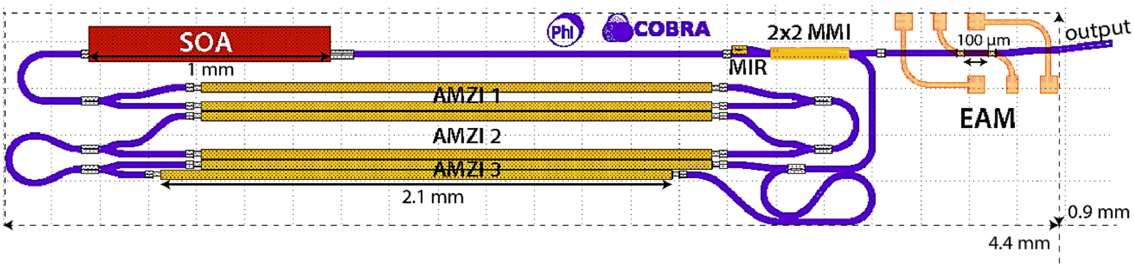


*Figure 1.* Mask layout of the photonic integrated circuit consisting of the extended cavity ring laser and the electro-absorption modulator The laser consists of a SOA section providing the gain, a wavelength tunable filter based on series of asymmetric Mach-Zehnder interferometers, multiple MMIs, a MIR reflector and multiple passive curved waveguides to connect all the components. The EAM section has a length of 100 µm and its footprint in this design is enlarged due to the metallization configuration for driving the modulator. The total area of the circuit is ~4 mm$^2$.

## Static characteristics

The presented photonic integrated chip was fabricated and mounted on an aluminum submount. As a first trial, the electrical contacts in the laser section were wire-bonded to a PCB for electrical signal distribution. This eases the access and the control of the extended cavity ring laser. The modulator section was driven with on-chip RF-probes (see Figure 2). A passive water cooling system has been used for temperature stabilization. The optical signal is collected with an AR-coated lensed fiber and further guided via a single mode fiber to the measurement equipment. The current injected in the SOA and the temperature of the system are kept constant, 120 mA and 18$^{o}$C, respectively.

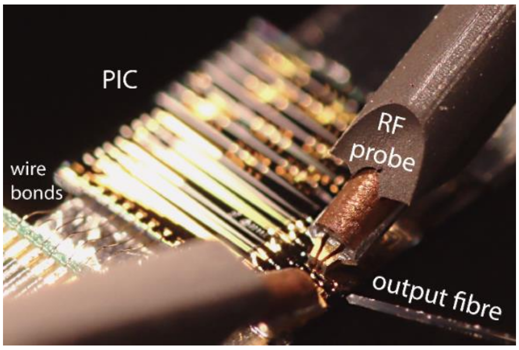


*Figure 2.* Close-up photograph of the measurement setup: laser is wire bonded to a PCB and driven externally, whereas the EAM is driven on-chip. The tilted output is collected with a lensed fiber and monitored externally. The mask layout shown in Figure 1 occupies one quarter of the PIC on the photo.

Applying different reverse voltages to drive the AMZI, we achieved the tuning of the laser of 56 nm, spanning from 1514 nm to 1570 nm. However, not all of this range is used for the operation with the modulator. As the EAM's bandgap is around 1550 nm, we've tuned the laser to the long wavelength range in order to decrease the insertion loss of the modulator.

When the modulator was in an open circuit configuration the output power of the PIC was 0 dBm. Applying 0 V bias to the EAM, we get its insertion loss ranging from 7 dB at 1560 nm, to 4 dB at 1570 nm. In Figure 3 (a) we can see a normalized received optical power and the modulator's static extinction ratio with a maximum of 9.4 dB for a reverse bias of 3.2 V. As the detuning wavelength is small, the applied reverse bias quickly reaches the point of absorbing most of the incoming light. The slope remains almost unchanged for different detuning wavelengths. As we increase the detuning of the laser a higher voltage needs to be applied to reach the absorption point, therefore the exciton peak shifts to the left in Figure 3 (a).

## Dynamic characteristics

For the dynamic measurements we tune the laser to the longest wavelength, 1570 nm, obtaining around 15 nm detuning. A small-signal measurement of the EAM gives its electro-optical (E/O) bandwidth, which is an indication of the bit rate that can be achieved. The measured E/O bandwidth of this EAM is ~13 GHz, shown in Figure 3 (b). This bandwidth allowed us to further measure the bit error rate (BER) of the system at 10 Gbps. For this measurement no erbium-doped fiber was used in order to avoid its noise contribution. The operating DC bias point was −2 V and the pseudo-random-bit-sequence (PRBS) length used $2^7-1$. The BER testing equipment has an internal receiver with a sensitivity of −9 dBm at $10^{-9}$ bit error ratio, therefore the received optical power is limited due to this reason. From Figure 3 (c) one can see that the power level enabling a BER of $10^{-9}$ is around −8 dBm for back to back measurement, quite close to the reference level of −9 dBm.

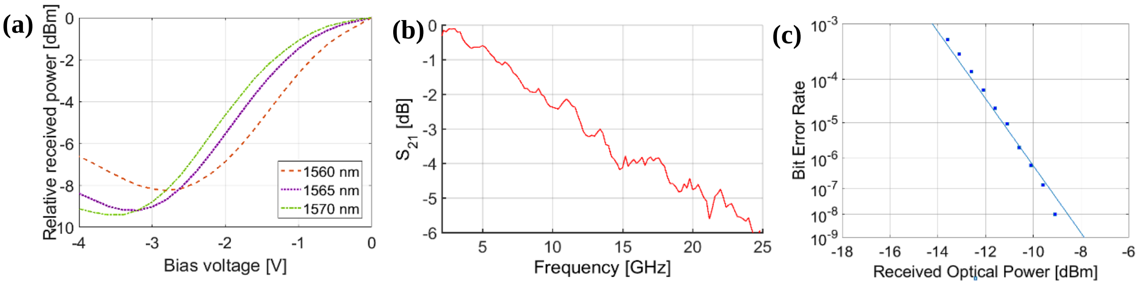


*Figure 3.* (a) Measured extinction ratio of the EAM with 120 mA injected in the SOA section and different lasing wavelengths. (b) Electro-optical bandwidth of the modulator section is measured to be ~13 GHz, which allowed the operation at 10 Gbps. (c) Bit error rate back-to-back curve for 10 Gbps.

## Summary

We have demonstrated the operation of a monolithically integrated widely tunable laser and electro-absorption modulator with an identical active layer stack. The circuit was designed and fabricated in the COBRA generic integration platform. We have shown the operation of the modulator at different lasing points. Because the same active layer stack was used for the amplifier in the laser section and the modulator, the detuning wavelength could not be optimized separately. The fairly high static extinction ratio of 9.4 dB for a 100-µm-long EAM and its E/O bandwidth allowed us to obtain an error-free back-to-back BER measurement at 10 Gbps.


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## References


[1] R. Nagarajan, M. Kato, J. Pleumeekers, P. Evans, S. Corzine, S. Hurtt, A. Dentai, S. Murthy, M. Missey, R. Muthiah, R. A. Salvatore, C. Joyner, R. Schneider, M. Ziari, F. Kish and D. Welch, "InP Photonic Integrated Circuits," *IEEE Journal of Selected Topics in Quantum Electronics,* vol. 16, no. 5, pp. 1113-1125, 2010.

[2] M. Smit et al, "An introduction to InP-based generic integration technology," *Journal Semiconductor Science and Technology,* no. 8, pp. 1-41, 2014.

[3] H. Klein, C. Bornholdt, G. Przyrembel, A. Sigmund, W. Molzow and M. Moehrle, "40 Gbit/s identical layer InGaAlAs-MQW electroabsorption- modulated DFB-lasers operating between 1298 nm and 1311 nm," in *Indium Phosphide and Related Materials*, Santa Barbara, 2012.

[4] P. Gerlach, "Up to 40 Gbit/s Operation of Laser-Integrated Electroabsorption Modulator Using Identical InGaAlAs Quantum Wells," Optoelectronics Department, University of Ulm, Ulm, 2004.

[5] B. Mason, G. A. Fish, S. P. DenBaars and L. A. Coldren, "Widely Tunable Sampled Grating DBR Laser with Integrated Electroabsorption Modulator," *IEEE Photonics Technology Letters,* vol. 11, no. 6, pp. 638-640, 1999.

[6] Y. A. Akulova, G. A. Fish, P. Koh, C. L. Schow, P. Kozodoy, A. P. Dahl, S. Nakagawa, M. C. Larson, M. P. Mack, T. A. Strand, C. W. Coldren, E. Hegblom, S. K. Penniman, T. Wipiejewski and L. A. Coldren, "Widely Tunable Electroabsorption-Modulated Sampled-Grating DBR Laser Transmitter," *IEEE Journal of Selected Topics in Quantum Electronics,* vol. 8, no. 6, pp. 1349-1357, 2002.

[7] S. Latkowski, A. Hänsel, N. Bhattacharya, T. de Vries, L. Augustin, K. Williams, M. Smit and E. Bente, "Novel Widely Tunable Monolithically Integrated Laser Source," *IEEE Photonics Journal,* vol. 7, no. 6, December 2015.

[8] M. Trajkovic, H. Debregeas, K. A. Williams and X. J. M. Leijtens, "20 Gbps operation of the electro-absorption modulator in the COBRA generic integration platform," in *18th European Conference on Integrated Optics*, Warsaw, 2016.